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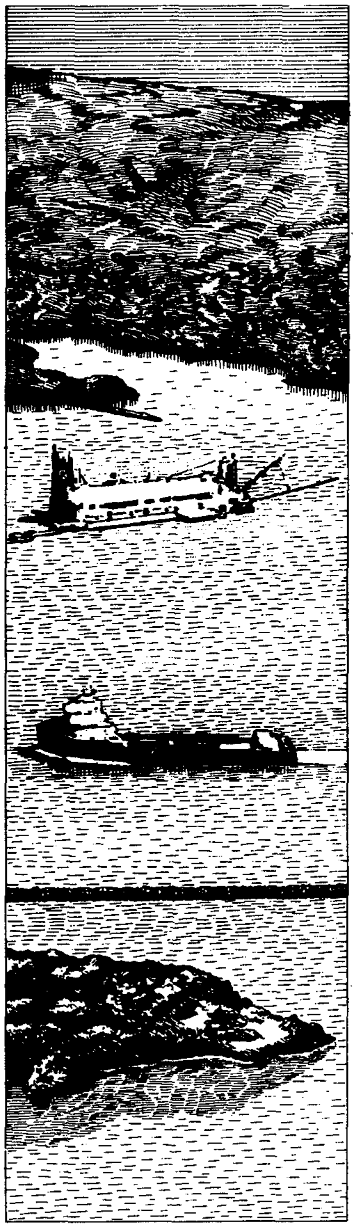

DREDGING RESEARCH PROGRAM

TECHNICAL REPORT DRP-96-2

MANAGEMENT OF DREDGING PROJECTS; SUMMARY REPORT FOR TECHNICAL AREA 5

compiled by

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DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

February 1996

Final Report

Prepared for DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit 32492

The Dredging Research Program (DRP) is a seven-year program of the U.S. Army Corps of Engineers. DRP research is managed in these five technical areas:

Area 1 - Analysis of Dredged Material Placed in Open Water
Area 2 - Material Properties Related to Navigation and Dredging
Area 3 - Dredge Plant Equipment and Systems Processes
Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
Area 5 - Management of Dredging Projects

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US Army Corps
of Engineers
Waterways Experiment
Station

Dredging Research Program
Report Summary

Management of Dredging Projects; Summary Report for Technical Area 5 (TR DRP-96-2)

ISSUE: The navigation mission of the Corps of Engineers entails maintenance dredging of about 40,000 km of navigable channels at an annual cost of about $400 million. Deficiencies in the dredging program have been documented by the Corps field operating Division and District offices. Implementation of the Dredging Research Program (DRP) to meet demands of changing conditions related to dredging activities, and the generation of significant technology that will be adapted by all dredging interests, are means to reduce the cost of dredging the Nation's waterways and harbors and save taxpayer dollars.

RESEARCH: The investigations of DRP Technical Area 5, "Management of Dredging Projects," developed a framework for comprehensive site management of the open-water placement and monitoring of dredged sediments, designed criteria for level-bottom capping and contained aquatic disposal of contaminated dredged materials, provided engineering design guidance for nearshore berms constructed of clean sediments, compiled a chronology of major events in the Corps' hopper-dredging program since 1954, and prepared a revised Engineer Manual on dredging. Also, an analysis was made of benefits to be obtained by use of the products developed by the DRP.

SUMMARY: A framework for long-term management of open-water sites based on guidance from Corps Headquarters in response to amendments of the Marine Protection, Research, and Sanctuaries Act (Ocean Dumping Act) was developed. A chronology of major events in the Corps' hopper-dredging program since publication of the "Red Book" in 1954 was compiled. Guidance for design of subaqueous dredged material capping projects was developed. The DRP benefits analysis accurately documented and quantified the tax dollars that could be saved by using products of the DRP. It was determined at the 90-percent confidence level that in 1994 dollars, annual recurring benefits of $17 million and annual one-time benefits of $19 million could accrue, and 5-year recurring and 5-year one-time benefits in excess of $100 million each could result from use of DRP products.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service report numbers may be requested from WES Librarians. To purchase a copy of the report, call NTIS at (703) 487-4780.

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Dredging Research Program

Technical Report DRP-96-2
February 1996

Management of Dredging Projects; Summary Report for Technical Area 5

Compiled by Lyndell Z. Hales

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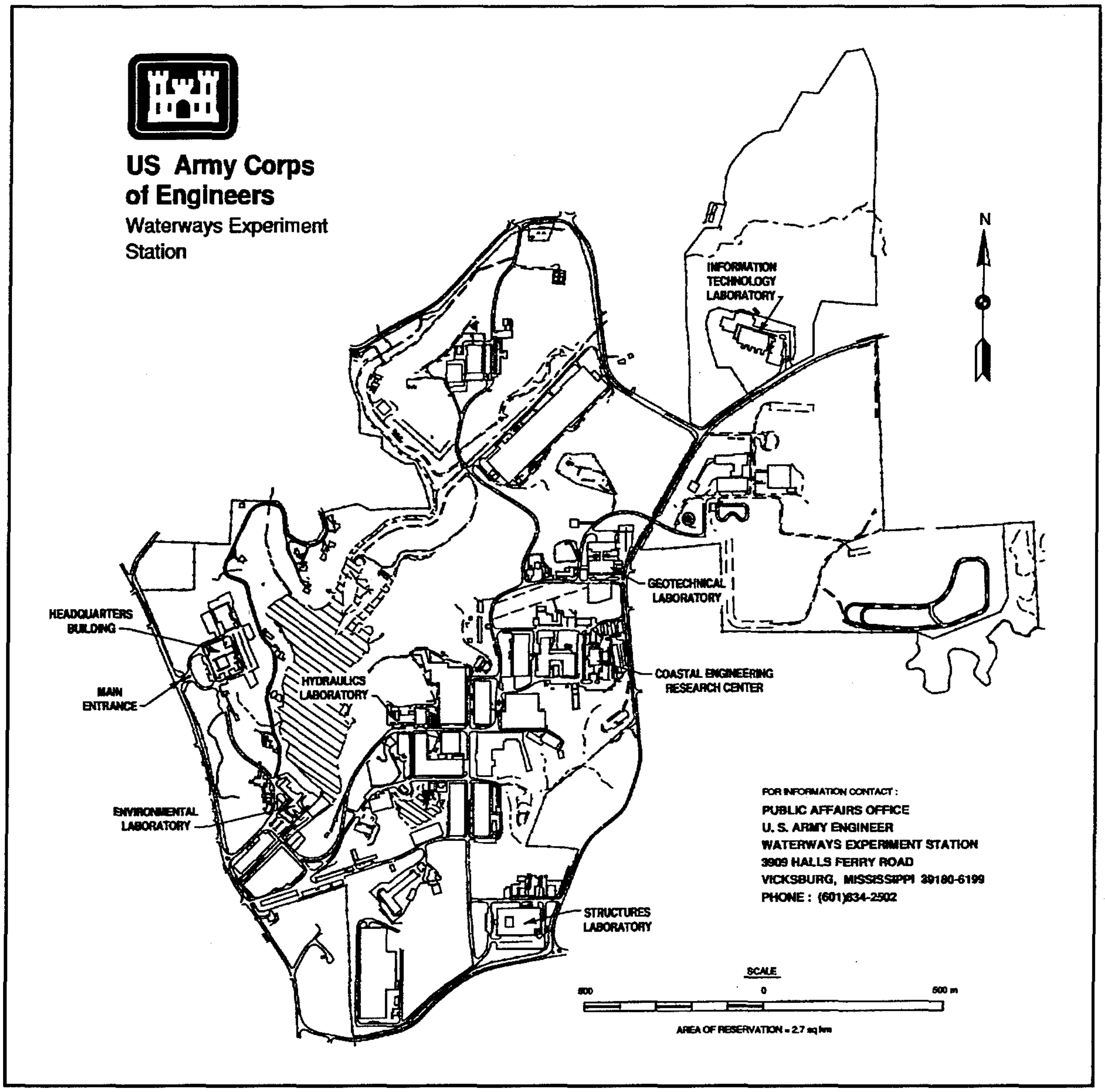

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Preface

This report summarizes research conducted under U.S. Army Engineer Waterways Experiment Station (WES) Dredging Research Program (DRP) Technical Area 5, "Management of Dredging Projects." The DRP was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Technical Monitor for Technical Area 5 was Mr. John G. Housley, HQUSACE. Chief Technical Monitor was Mr. Robert H. Campbell (retired), HQUSACE.

This summary report was compiled by Dr. Lyndell Z. Hales, Coastal Engineering Research Center (CERC), WES, and was extracted essentially verbatim from Technical Area 5 reports.

Technical Area 5 studies were conducted by or under the following WES supervision:

CERC—Mr. James E. Clausner, Principal Investigator, Coastal Structures and Evaluation Branch (CSEB), Engineering Development Division (EDD); Dr. Nicholas C. Kraus; and Mses. Cheryl E. Burke (Cheryl B. Pollock), Sandra K. Lemlich, and Mary C. Allison and Mr. T. Neil McLellan, CSEB. Additional supervision was provided by Ms. Joan Pope, Chief, CSEB; Mr. Thomas W. Richardson, Chief, EDD; Mr. Charles C. Calhoun, Jr., Assistant Director, CERC; and Dr. James R. Houston, Director, CERC.

Environmental Laboratory (EL)—Dr. Michael R. Palermo, Special Projects Group, Environmental Engineering Division (EED); and Dr. Thomas D. Wright, FATES and Effects Branch (FEB), Environmental Processes and Effects Division (EPED). Additional supervision was provided by Dr. Norman R. Francingues, Chief, EED; Dr. Raymond L. Montgomery (retired), former Chief, EED; Dr. Bobby L. Folsom, Chief, FEB; Dr. Donald L. Robey, Chief, EPED; Dr. John W. Keeley, Director, EL; and Dr. John Harrison, former Director, EL.

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Mr. Richardson was the Technical Area Manager for Technical Area 5.

Mr. E. Clark McNair, Jr., CERC, and Dr. Hales were Manager and Assistant Manager, respectively, of the DRP. Dr. Houston and Mr. Calhoun were Director and Assistant Director, respectively, of CERC, which conducted the DRP.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

For further information on this report or on the Dredging Research Program, please contact Mr. E. Clark McNair, Jr., DRP Program Manager, WES, at (601) 634-2070.

Conversion Factors, Non-SI to Si (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
barrels	0.159	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers
square miles	2.58999	square kilometers

Summary

This report summarizes research conducted by the WES DRP Technical Area 5, "Management of Dredging Projects," to develop guidelines for open-water dredged material disposal site planning, design, and management practices for long-term availability of such sites. A chronology of Corps hopper-dredging activities since 1954 also was provided. Finally, a benefits analysis of the usefulness of products developed by the DRP was performed.

"Open-Water Disposal Site Planning, Design, and Management" provided a framework for long-term management of open-water sites based on guidance from Corps Headquarters in response to amendments of the Marine Protection, Research, and Sanctuaries Act (Ocean Dumping Act). Design requirements for capping of contaminated sediments placed in open-water sites were developed. Design guidance for nearshore berm construction was produced from numerical model simulations of both feeder and stable berms.

"Dredging Manuals" prepared *Corps of Engineers Hopper Dredging, 1954-1994*, a chronology of major events in the Corps' hopper-dredging program since publication of the "Red Book." The Red Book represented an era when no private industry hopper dredges existed in the United States and the Corps owned and operated 20. In the interim since the Red Book was published, policy changes, including the industry capability program, have caused the Corps hopper-dredge fleet to shrink to four at the present time: two on the west coast (*Yaquina* and *Essayons*); one on the east coast (*McFarland*); and one on the Gulf coast (*Wheeler*). The minimum fleet study mandated by PL 95-269 concluded that hopper-dredging capability should not necessarily be the Corps' responsibility and that existing military needs in themselves do not require a Corps minimum fleet. Fifteen privately owned hopper dredges presently operate in the United States. Also, a new Engineer Manual (EM) was prepared to replace the existing EM 1125-2-312, and provides guidance on current operating and reporting procedures for hopper and sidecasting special-purpose dredges.

"Dredging Research Program Benefits Analysis" conducted a benefits analysis to accurately document and quantify in tax dollars saved the economic benefits from using products of the DRP. Each Corps project nationwide was analyzed to see whether a product developed by the DRP

would have produced a tangible savings on that project. It was determined that, at the 90-percent confidence level in 1994 dollars, annual recurring benefits of $17,404,000 and annual one-time benefits of $19,047,000 could accrue for total annual benefits of $36,451,000, and 5-year recurring and 5-year one-time benefits of $100,586,000 and $101,141,000, respectively, could result for total projected 5-year benefits of $201,727,000 from use of DRP products.

1 Introduction

The U.S. Army Corps of Engineers (USACE) is involved in virtually every navigation dredging operation performed in the United States. The Corps' navigation mission entails maintenance and improvement of about 40,000 km of navigable channels serving about 400 ports, including 130 of the Nation's 150 largest cities. Dredging is a significant method for achieving the Corps' navigation mission. The Corps dredges an average annual 230 million cu m of sedimentary material at an annual cost of about $400 million. The Corps also supports the U.S. Navy's maintenance and new-work dredging program (McNair 1989).

Background

Genesis of the Dredging Research Program

Significant changes occurred in the conduct of U.S. dredging operations and the coordination of such dredging with environmental protection agencies as a result of the National Environmental Policy Act of 1969. Subsequent Federal legislation authorized a study of the ability of private contractors to perform the Nation's required navigation dredging activities. That study determined that, from national emergency considerations, only a minimal Federal dredge fleet was necessary, and the bulk of hopper-dredge activities shifted from the once large Corps fleet to private sector contract hopper dredges (Hales 1995).

A long period in which the Corps' dredging activities consisted almost totally of maintaining existing waterways and harbors changed with passage of the Water Resources Development Act of 1986. This legislation authorized major deepening and widening of existing navigation projects to accommodate modern Navy and merchant vessels. Future changes in dredging are not expected to be any less dramatic than those which occurred in recent years. The Corps will continue to be challenged in pursuing optimal means of performing its dredging activities. Implementation of an applied research and development program to meet demands of changing conditions related to Corps dredging activities and the generation

of significant technology that will be adopted by all dredging interests are means of reducing the cost of dredging the Nation's waterways and harbors.

Dredging Research Program

The concept of the Dredging Research Program (DRP) emerged from leadership of Headquarters, USACE (Navigation and Dredging Division and Directorate of Research and Development (CERD)) in the mid-1980s (McNair 1988). It was realized early in the program development that research should be directed toward addressing documented deficiencies identified by the primary Corps users, namely the field operating Division and District offices. Problems identified by the field offices were formulated into specific applied research work tasks describing objectives, research methodologies, user products, and time/cost schedules. CERD delegated primary responsibility for developing the DRP to the U.S. Army Engineer Waterways Experiment Station. The 7-year, $35-million DRP, initiated in FY88, achieved all major milestones, goals, and objectives scheduled in the program-planning process.

A major DRP objective was the development of equipment, instrumentation, software, and operational monitoring and management procedures to reduce the cost of dredging the Nation's waterways and harbors to a minimum consistent with Corps mission requirements and environmental responsibility. The DRP consisted of the following five technical areas, from which many distinct products were generated and annual and one-time direct and indirect benefits were quantified.

a. Technical Area 1: Analysis of Dredged Materials Disposed in Open Water.

b. Technical Area 2: Material Properties Related to Navigation and Dredging.

c. Technical Area 3: Dredge Plant Equipment and Systems Processes.

d. Technical Area 4: Vessel Positioning, Survey Controls, and Dredge Monitoring Systems.

e. Technical Area 5: Management of Dredging Projects.

Technical Area 5

Objectives of Technical Area 5, "Management of Dredging Projects," included (a) development of a framework for comprehensive site management of the open-water placement and monitoring of dredged sediments, (b) design requirements for level-bottom capping and contained aquatic disposal of contaminated dredged materials, (c) engineering design guidance for nearshore berms constructed of clean sediments, and (d) a chronicle

compilation of major events in the Corps of Engineers hopper-dredging program since publication of *The Hopper Dredge: Its History, Development, and Operation* in 1954, otherwise known as the "Red Book." An updated version of EM 1125-2-312 pertaining to hopper and sidecasting/special-purpose dredging operations and reporting procedures was developed. Also an analysis was made of the benefits to be obtained by use of the products developed by the DRP. Research areas of Technical Area 5 included:

a. Open-Water Disposal Site Planning, Design, and Management.

b. Dredging Manuals.

c. Dredging Research Program Benefits Analysis.

Report Organization

Chapter 2 of this Summary Report of Technical Area 5 discusses (a) the necessity for complying with over 30 major environmental statutes that govern the way open-water disposal of dredged material is managed in the United States, (b) design guidance for capping contaminated sediments disposed in open water, including equipment and placement techniques, and (c) engineering design considerations for nearshore berms as an alternative to conventional open-water placement and for beneficial uses of suitable dredged materials.

Chapter 3 provides an historical account of Corps hopper-dredging activities for the period 1954-1994.

Chapter 4 discusses the first benefits/costs analysis of a Federal research and development program and documents the savings to be gained by applying the numerous DRP-developed products to the Corps national dredging program.

Chapter 5 is a synopsis of Technical Area 5 reports pertaining to technology and analyses developed by the DRP for ensuring the long-term availability of open-water placement sites for clean and contaminated dredged sediments through better estimating techniques and comprehensive management of dredging projects.

2 Open-Water Disposal Site Planning, Design, and Management[1]

The primary Federal environmental statute governing transportation of dredged material to the ocean for purposes of disposal is the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972, also known as the Ocean Dumping Act. The primary Federal environmental statute governing the discharge of dredged and/or fill material into waters of the United States is the Federal Water Pollution Control Act of 1977, also called the Clean Water Act (CWA). All proposed dredged material disposal activities regulated by MPRSA and CWA must also comply with the applicable requirements of the National Environmental Policy Act (NEPA) and its implementing regulations. In addition to MPRSA, CWA, and NEPA, there are numerous other Federal laws, Executive Orders, etc., that must be considered in the evaluation of dredging projects (Palermo, Randall, and Fredette; in preparation). These legislative acts not only cover the deposition of dredged material for disposal purposes, but also apply to placement of otherwise clean material for beneficial purposes such as the construction of nearshore berms in the coastal zone to maintain littoral transport or wave-energy attenuation.

Framework for Site Management

Section 103 of the MPRSA and Section 404 of the CWA assign responsibility for regulating dredged-material discharges to the Secretary of the Army. Managing open-water sites used for placement of dredged sediments is an essential and integral component of these responsibilities (Walls et al., in preparation).

1 Chapter 2 was extracted from sources cited in the text.

Open-water sites used for placement of dredged sediments are selected and managed to facilitate the necessary dredging and subsequent disposal of dredged sediments, while minimizing potential adverse impacts to human health or to the aquatic environment. For many navigation projects that are vital to the Nation's economic health, placing dredged material in open-water sites is often the least costly alternative. However, as public awareness and concern for the aquatic environment have increased, open-water placement of dredged sediments has become subject to increased public awareness and environmental concern. Continued use of aquatic sites for placement of dredged sediments may depend on the Corps' ability to effectively manage dredged-material placement sites, as well as on the perception of how well the Corps' management policies and practices protect human health and the aquatic environment.

Requirements for long-term management

In addition to compliance with all applicable Federal statutes, several USACE policies guide site management. First, Federal budgetary interest in construction and in continuing operation and maintenance of Federal projects is defined by the least-cost plan for dredged material management that is consistent with sound engineering practices and Federal environmental laws. Accordingly, site management is partially shaped by cost considerations. Second, it is USACE policy to undertake dredging and dredged material management activities to achieve maximum useful life for dredged material disposal sites. Therefore, site management often focuses on maintaining continued use of existing placement sites. Third, Corps District Engineers are urged to identify and develop long-term management plans for placement of dredged sediments from Federal projects. Hence, the focus of site management must be long-term.

Management efforts must be tailored to each placement site. Conservatively, there are several thousand open-water placement sites in use nationwide. Site characteristics can be extremely diverse. A dispersive site receiving sand-sized sediments may require only minimal management to ensure that physical impacts, such as unacceptable mounding, do not occur. Conversely, multiple-user regional sites may likely require intensive management to ensure an adequate level of environmental protection.

Expanded guidance on managing open-water dredged material placement sites is being prepared as a joint effort by USACE and the U.S. Environmental Protection Agency (USEPA). Moreover, recent amendments to the MPRSA call for specific site-management activities and preparation of site-management plans for all ocean placement sites. Present Corps policy (May 1994) describing the funding and elements of studies for dredged material management associated with existing Federal navigation projects and feasibility studies for modifying Federal projects are found in Policy Guidance Letters Nos. 40 and 42, respectively (USACE 1993a, 1993b).

Benefits of site management

Effective site management can provide numerous benefits. The principal benefits are derived through ensuring the long-term availability of the placement site: (a) potential project delays are avoided; (b) costs of identifying and designating/specifying alternative sites are saved; and (c) potential increases in transportation costs or other costs relative to alternative sites are averted. Effective site management can also (a) increase regulatory efficiency, (b) ensure compliance with applicable Federal statutes and regulations, (c) reduce conflicts with other uses of the aquatic environment, (d) minimize adverse environmental impact, (e) ensure maintenance of safe and efficient navigation, (f) optimize site use, and (g) ease public concerns regarding aquatic placement of dredged material.

Additionally, site management can facilitate placement of dredged material requiring special handling, allow placement of dredged material in special areas such as capped disposal sites and nearshore berm construction, or provide for other innovative alternatives for placement of dredged material.

Components of site management

All sites are unique, and management responsibilities will vary from site to site. Typically, site-management programs include the following elements:

a. Developing and implementing a formal site-management plan based on the types and quantities of dredged sediment, site-specific characteristics, dredging equipment, and issues of local or regional concern.

b. Regulating time, rates, and methods of placement, as well as quantities and types of dredged material placed.

c. Ensuring compliance of placement activities and enforcement of applicable regulations, permit conditions, and contract specifications.

d. Developing and implementing effective monitoring programs for the open-water sites.

e. Managing data and reporting monitoring results and conditions at the site.

f. Coordinating site-management actions and site use.

g. Evaluating effects of continued use of the site for placement of dredged sediment.

h. Recommending modifications in, or termination of, site use or designation/specification.

USACE approach

The USACE approach to managing open-water sites focuses on providing all necessary information for site managers to make informed decisions. All of the proposed components of management programs must be implementable, cost-effective, practical, enforceable, and clearly applicable to the decision-making process.

Proactive site management involves early action to prevent or minimize undesirable effects. Sites are selected to minimize impact to the aquatic environment and minimize interference with other uses of the Nation's waters. Critical resources near the disposal site are identified, the range of potential impacts from dredged material placement is evaluated, and management is focused on preventing unacceptable adverse impacts to these resources. Dredged material proposed for placement at open-water sites is carefully evaluated and screened before placement. When appropriate, the times, rates, and quantities of dredged material placement can be regulated to minimize adverse impacts or maximize site capacity.

A written site-specific management plan can greatly facilitate management action over the extended use of the placement site. For some sites, the best plan will be flexible and evolving, and written plans will need to be updated periodically. Site-management plans can provide continuity of management policy and procedures and can support consistent planning and decision making. The plan can also define site-management roles and responsibilities. Moreover, the management plan provides for a systematic approach to site management. Previous management decisions are clarified for present and future managers, and appropriate and adequate management actions are delineated. The greatest advantage of a site-management plan, however, may be that it can focus decision makers on the overall management issues associated with placement of dredged material that warrant further consideration or continuing evaluation.

Site monitoring

Monitoring is an essential component in the overall management of a site. The feasibility and efficacy of monitoring often are considered when selecting placement sites, and monitoring studies can be used to confirm predictive determinations made in the site specification/designation and in issuing permits. Accordingly, monitoring studies should focus on providing useful compliance information to site managers.

Monitoring plans must be appropriate for the type and quantity of dredged material, the site characteristics, and the site environment. As with other management activities, the intensity of monitoring will increase

with (a) the volume of dredged material, (b) the rate of placement, (c) the number of site users, (d) the variability of sediments, (e) the presence of man-made contaminants in the sediment, and (f) resources of concern in the vicinity of the placement site. At a carefully selected site, under the best conditions, the appropriate level of monitoring is minimal. Results of monitoring studies conducted at other dredged material placement sites should be considered whenever appropriate.

Well-designed monitoring can be a powerful management tool. Monitoring can provide specific evidence to support or modify site-management plans and practices. Decisions that were made when the site was specified/designated or when permits were issued can be confirmed or shown to need modification. Results of monitoring studies can be used to verify assumptions and predictions or to provide a basis for modifying the decision process (i.e., developing more or less stringent decision guidance).

Define unacceptable impact. To effectively use monitoring as a management tool, site managers need to define in quantitative terms the unreasonable or unacceptable effects that dredged material may have on resources of concern. In the same manner, early-warning action levels should be determined in advance of monitoring studies. The action levels should represent a level of effects well below those effects defined as unreasonable or unacceptable. This allows the site managers to take corrective measures if action-level effects are observed and thus prevent unreasonable and unacceptable effects.

Prospective monitoring. Where practicable, monitoring programs should be prospective (i.e., consisting of repeated observations or measurements to determine if site conditions conform to a predetermined and quantifiable standard or baseline). Unreasonable degradation and unacceptable adverse effects are defined, and resources that might be at risk, both near field and far field, are identified before sampling or field studies begin. Additionally, specific early-warning thresholds of physical, chemical, and biological conditions that should not be exceeded are established, and impacts of the dredged material placement are predicted. If impacts approach these specific early-warning thresholds, operations can be modified or terminated long before unacceptable impacts occur.

Tiered approach. A strategy for developing and implementing monitoring programs for disposal sites has been designed to provide site managers with reliable cost-effective information on the effects of disposal of dredged material into the aquatic environment. This strategy follows a tiered approach driven by several key principles. In general, a tiered monitoring program will proceed through the development of a series of predictions regarding the transport, fate, and impact of disposed dredged material. Many of these predictions will be shaped by the site-selection and site-designation process.

Each tier should have defined unacceptable thresholds, null hypotheses, and sampling/data-collection plans, plus predetermined management

options if the threshold is exceeded. In a tiered approach, each defined objective is monitored by testing a series of null hypotheses. Results that indicate the acceptance of the null hypothesis at any tier would prevent further, often more costly, monitoring at a more complex level. Results that indicate rejection of the null hypothesis will trigger monitoring in higher tiers and provide early indication to managers that a predetermined adverse effect may occur. This approach allows managers to take corrective actions and modify disposal activity before unacceptable impact occurs.

Multi-user sites. Multi-user sites (those used by multiple Federal projects and private permittees) often create additional management challenges. Multi-user sites are becoming more widespread as a result of the environmental and economic difficulties in designating new sites. Because the Corps issues the permits, it controls and has ultimate responsibility for the sites and therefore should be responsible for site management. However, as proponents for permit projects are asked to cost-share in monitoring and other aspects, they demand a greater role in the management process, thus making the job of the site manager more complicated. Some of the obvious problems include less control of the timing and volumes of material that go into the site and increased requirements for inspection, monitoring, and data management. Often, innovative methods must be developed to fund the increased monitoring that is required. Probably the only universal truth is to get those involved together early and often, both to educate and to seek input.

Management tools and alternatives

For all sites, managers should strive to determine in advance the complete range of management tools and actions that are to be employed when triggered by specified impacts or conditions. Careful analysis is required to ensure that all management tools are implementable and to identify and ensure the availability of the resources necessary for implementing these alternatives, including closure of the site.

Data management and reporting

The extent to which a site-management plan succeeds will depend on how closely the generated data fit the needs of the site managers and how quickly the information reaches managers for decision making. If the information provided is not linked to specific concerns or management decisions, it may be of little value. In addition, data must be in a format and of sufficient quality to be useful to site managers and available within a reasonable amount of time.

Regulating Use of Placement Sites

The site-selection process or the site-management plan may set limits or restrictions on the type and the quantity of dredged material that may be disposed at the site. Some typical limits and restrictions include quantity limits, rate of dredged material placement, and seasonal restrictions.

Sediment evaluation/testing requirements. The primary purpose of sediment testing and evaluation is to determine whether the sediment is suitable for open-water disposal. Data generated during this process are useful for the management plan as it will indicate the quantity and nature of sediment that may be placed at an open-water site as well as the subsequent behavior of the material, such as erosion, transport, and consolidation. These behavioral characteristics are important in determining site capacity and in protecting resources outside the boundaries of the site and are frequently useful in the design of monitoring activities.

Disposal-site history. The site-management plan can be updated periodically to provide a summary description of the dredged material disposal activity that has taken place at the site. Information that may be of benefit includes:

a. Known historical uses of the proposed disposal site. Site plans may include a comprehensive listing or a summary of recent activity. The dates of dredged material disposal, the volume of dredged material, and a concise description of the grain size, geotechnical properties, chemical characteristics, and bioassay and bioaccumulation test results may be included.

b. Review of transportation and disposal methods, conditions experienced, observations, lessons learned, difficulties, and similar information.

c. Findings of monitoring studies that have been conducted at the site (i.e., documented effects of other authorized placements that have been made in the disposal area).

Project conditions. The Corps District Engineer may impose specific conditions on projects requiring placement of dredged material at open-water sites. These conditions may range from specifying the type of equipment to be used to requiring participation in or sponsorship of specific monitoring studies. Those project conditions relative to the management of the site, specifically those conditions that site managers wish to have applied to all projects, may be itemized in the site-management plan. In addition to the topics mentioned above, subjects of such conditions may include:

a. Equipment requirements (e.g., equipment for dredging, transportation, and disposal; navigation; and positioning).

b. Disposal methods (e.g., only bottom dumps are allowed).

c. Positioning of discharge and allowable tolerances in position (e.g., position may be specified to localize areas of greatest benthic impact within the site).

d. Debris removal.

e. Overflow.

f. Spillage, leakage, and misplacement of dredged material.

g. Record-keeping and reporting requirements.

h. Inspection and surveillance.

i. Quality assurance/quality control.

j. Special study or monitoring requirements.

k. Other miscellaneous provisions.

Specialized management procedures

Material that is not suitable for unrestricted open-water disposal can sometimes be disposed at open-water sites by using specialized procedures such as (a) time, location, and volume modifications, (b) submerged discharge, (c) lateral containment, (d) thin-layer placement, (e) capping, or (f) in-line treatment. The site-management plan should identify the specialized tools and management practices appropriate for the site and specify the criteria leading to the use of such practices. Additional guidance on the process of evaluating these specialized procedures is provided in USEPA/USACE (1992).

Time, location, and volume modifications. Considerations for meeting water-quality standards or criteria or toxicity criteria may require modifications of the discharge regime. The management plan should incorporate such modifications. Examples include siting of the discharge within the disposal site so as not to exceed constraints outside the boundary of the site, discharging at times when currents are minimal or maximal, or reducing the volume of sediment in each discharge. Of necessity, these will be site-and sediment-specific, and the management plan should, if necessary, address these on a case-by-case basis.

Submerged discharge. Submerged discharge is a technique that may be considered to reduce or limit water-column impacts. The use of a submerged point of discharge reduces the area of exposure in the water column and consequently the amount of material suspended in the water column and susceptible to dispersion. The use of submerged diffusers

can also reduce the exit velocities for hydraulic placement, allowing more precise placement and reducing both resuspension and spread of the discharged material. Considerations in evaluating the feasibility of a submerged discharge or use of a diffuser include water depth, bottom topography, currents, type of dredge, and site capacity.

Lateral containment. Lateral containment is a control measure that can be considered to reduce the area of benthic impact or the potential release of contaminants. The use of subaqueous depressions or borrow pits or the construction of subaqueous dikes can provide lateral containment of material reaching the bottom. Considerations in evaluating the feasibility of lateral confinement include type of dredge, water depth, bottom topography, bottom sediment type, and site capacity. Simply selecting a site amenable to lateral confinement, such as an existing bottom depression or valley, can be effective. Placement of material in constructed depressions such as abandoned borrow pits has also been proposed. Submerged dikes or berms for purposes of lateral confinement have been constructed or proposed at several sites. Such a proposal would not necessarily involve significant added expense to the project if the material used for the berm comes from the same or another dredging project.

Thin-layer placement. Placement of dredged material in a thin layer over wide areas is a management action that may be considered to offset physical effects due to burial of benthic organisms. Thin-layer placement allows benthic organisms to more easily burrow up through newly placed material and also increases the rate of recolonization of the disposal site.

Capping and contained aquatic disposal. Capping is the controlled placement of a sediment at an open-water site followed by a covering or cap of sediment to isolate the original material from the adjacent environment. Capping is a means of controlling the benthic contaminant pathway. Level-bottom capping (LBC) is a term used for capping without means of lateral confinement. If some form of lateral confinement is used in conjunction with the cap, the term "contained aquatic disposal" (CAD) is used. Schematic representations of LBC and CAD are shown in Figure 1. Considerations in evaluating the feasibility of capping include site bathymetry, water depth, currents, potential for storm-induced erosion, physical characteristics of contaminated sediment and capping sediment, and placement equipment and techniques. It is generally perferable for capping to be conducted in low-energy environments. However, if low-energy sites are unavailable, capping can be conducted at high-energy sites. For capping at high-energy sites, studies are needed to determine the additional thickness of the outer layer for erosion protection, as well as for establishing the frequency of postdisposal monitoring.

Precise placement of material is necessary for effective capping, and the use of other control measurers such as submerged discharge and lateral containment increases the effectiveness of capping.

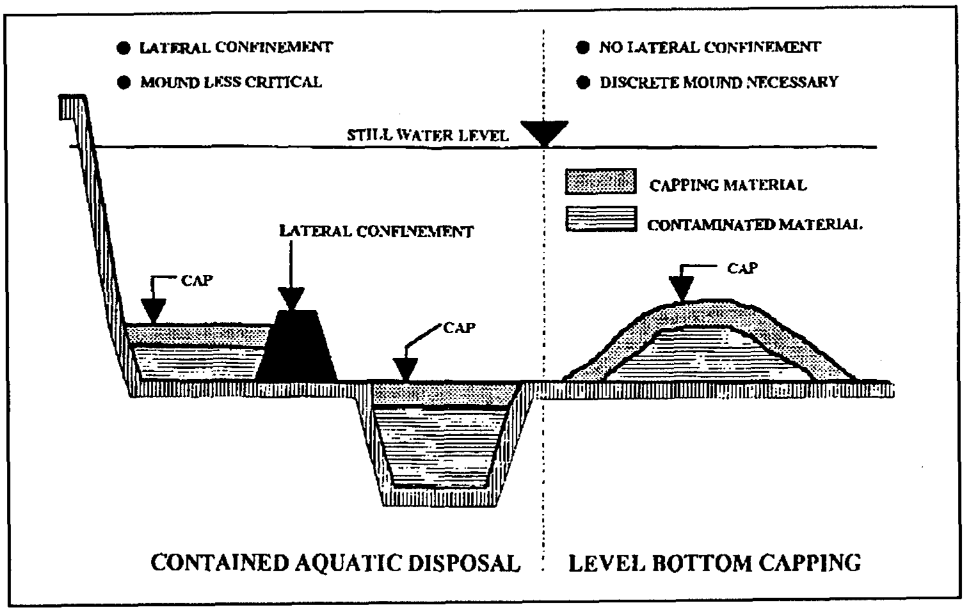

Figure 1. Schematic representation of CAD and LBC concepts

In-line treatment. Treatment of discharges into open water may be considered to reduce certain water-column or benthic impacts. For example, the Japanese have used an effective in-line dredged material treatment scheme for highly contaminated harbor sediments. However, this strategy has not been widely applied, and its effectiveness has not been demonstrated for solution of the problem of contaminant release during open-water disposal.

Capping Contaminated Sediments Disposed in Open Water

Potential for water-column and benthic effects related to sediment contamination must be evaluated when considering open-water disposal for dredged material. A majority of the material descends rapidly to the bottom; contaminants remain tightly bound to the sediment being disposed. Thus, the release of contaminants into the water column is not generally viewed as a significant problem for material dredged from most navigation projects. The acceptability of a given material for unrestricted open-water disposal is therefore mostly dependent on an evaluation of the potential benthic effects (Palermo, Randall, and Fredette; in preparation).

If a material is acceptable for unconfined open-water disposal, it is termed "suitable" or "clean" material. If a sediment is found to be unsuitable for open-water disposal because of potential contaminant effects (classified "contaminated" material), management options aimed at reducing the release of contaminants to the water column during disposal and/or

subsequent isolation of the material from benthic organisms may be considered. Such options include capping of contaminated material with suitable material.

Design and management sequence

Capping must not be viewed merely as a form of restricted open-water placement. A capping operation is treated as an engineered project with carefully considered design, construction, and monitoring to ensure that the design objectives are achieved. The basic criterion for a successful capping operation is that the cap thickness required to isolate the contaminated material from the environment be successfully placed **and** maintained.

The design requirements for an LBC or CAD project include characterization of both contaminated and capping sediments, selection of an appropriate site, selection of compatible equipment and placement techniques, prediction of water-column mixing and dispersion during placement, determination of the required capping sediment thickness, prediction of material spread and mounding during placement, evaluation of cap stability against erosion and bioturbation, and development of a monitoring program.

The flowchart shown in Figure 2 illustrates the design requirements for a capping project and the sequence of 14 events in which the design requirements should be considered. The stepwise sequence is summarized in Appendix A; details are given in Palermo, Randall, and Fredette (in preparation).

Equipment and techniques

Placement of capping material should be accomplished so that the deposit forms a layer of required thickness over the deposit of contaminated material. The surface area of a deposit of contaminated material to be capped may be several hundred meters or more in diameter. Placement of a cap of required thickness over such an area requires spreading the material to some degree to achieve coverage.

The equipment and placement technique should be selected, and the rate of application of capping material should be controlled to avoid displacement of or mixing with the previously placed contaminated material to the extent possible. Placement of capping material at equal or less density than the contaminated material would generally meet this requirement. While water-column dispersion of capping material would not usually be of concern, the use of submerged discharge (Figure 3) for capping placement can be considered from the standpoint of control during placement (Palermo 1991).

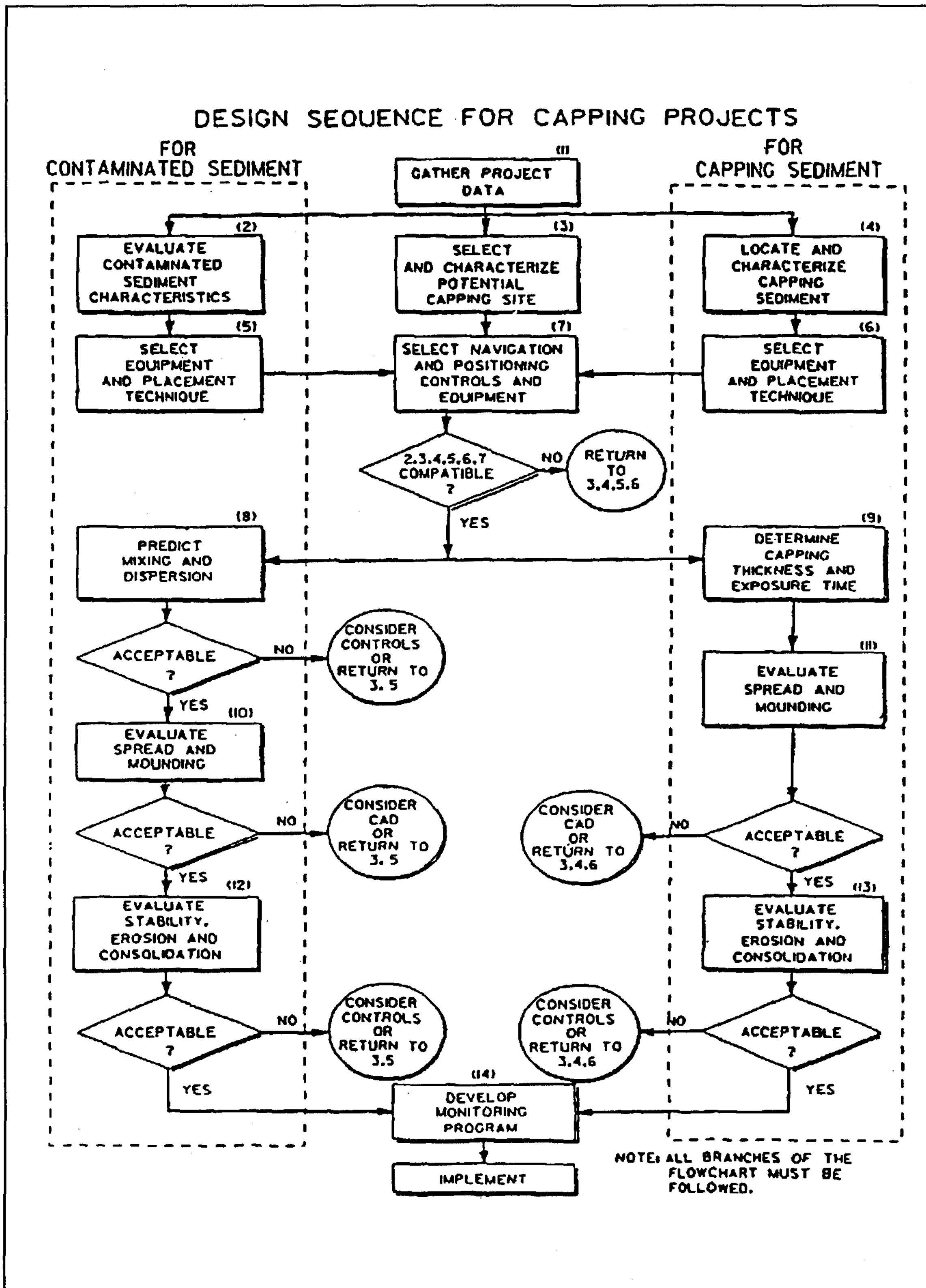

Figure 2. Design procedure for a capping project for open-water disposal of dredged material

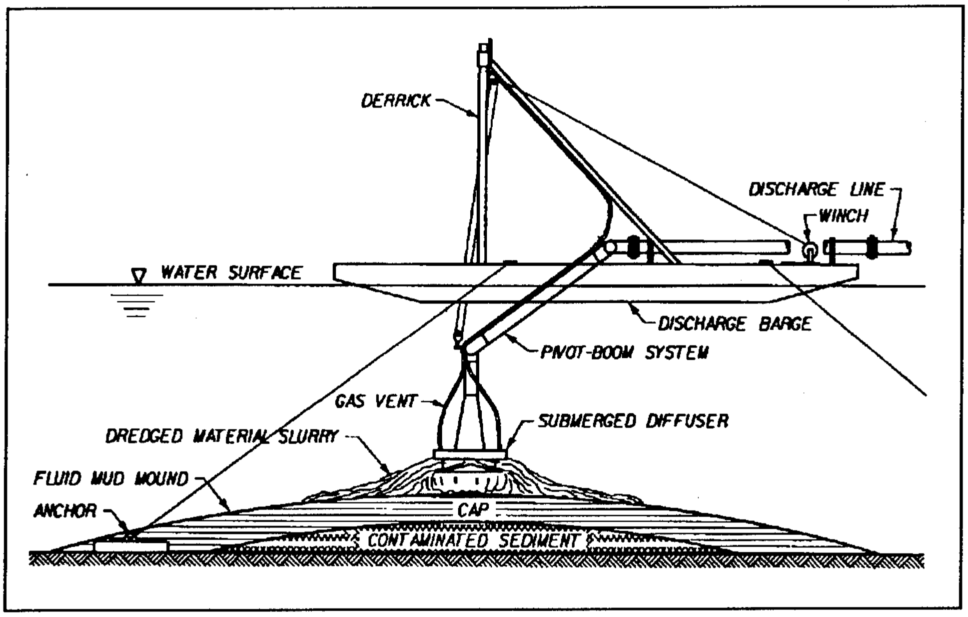

Figure 3. Submerged diffuser system

Cap design

Cap design consists of evaluating acceptable exposure time between contaminated material placement and cap placement, determining the minimum cap thickness for isolation and bioturbation, determining the design cap thickness to include components for erosion and consolidation, designing the operational controls for cap placement, and evaluating long-term cap effectiveness. Special design considerations for interim caps and for capping thin apron layers are required.

Determining the minimum required cap thickness depends on the physical and chemical properties of the contaminated and capping sediments and the potential for bioturbation of the cap by aquatic organisms. The thickness for chemical isolation plus the thickness for bioturbation is considered the minimum required cap thickness. This minimum required thickness must be maintained to ensure long-term integrity of the cap. The integrity of the cap from the standpoint of physical changes in cap thickness and long-term migration of contaminants through the cap should also be considered. The potential for a physical reduction in cap thickness due to the effects of consolidation and erosion can be evaluated once the overall size and configuration of the capped mound is determined. The design cap thickness can then be adjusted such that the minimum required cap thickness is maintained.

Chemical isolation. The thickness for chemical isolation is that required to obtain an effective chemical seal. This thickness can be determined by a laboratory capping-effectiveness test performed on samples of the contaminated and capping materials. Chemical isolation tests have

shown the minimum required cap thickness for chemical isolation to be on the order of 1 ft[1] for most materials.

Bioturbation. The thickness required for bioturbation is equivalent to the depth to which the deepest burrowing organism likely to colonize the site in significant numbers can reach. The importance of bioturbation by burrowing aquatic organisms to the mobility of contaminants cannot be overestimated. In addition to the disruption (breaching) of a thin cap that can result when organisms actively work the surface sediments, there is the problem of the direct exposure of the burrowing organisms to the underlying contaminated material. Bioturbation depths are highly variable, but have been on the order of 1 to 2 ft for most organisms that may populate a disposal site in great numbers. Consultation with experts on bioturbation in the region of the disposal-site location is desirable. The thickness needed to prevent breaching of cap integrity through bioturbation can be determined indirectly from other information sources. For example, the benthic biota of U.S. coastal and freshwater areas have been fairly well examined, and estimates of the depth to which benthic animals burrow should be available from regional authorities.

Erosion. Detailed methods for predicted erosion values must be used to determine the final value for the erosion thickness component. For projects in which no subsequent capping is anticipated (e.g., the final cap for a site) or for which materials for cap nourishment are not easily obtained, cap erosion thickness should be equivalent to the greater of erosion calculated for a period of 20 years of normal current/wave energies or a 100-year extreme event. For projects in which subsequent capping is planned or for which materials for cap nourishment can be easily obtained, higher erosion rates may be considered. In areas where available capping materials and current and wave conditions are severe, a coarse-grained layer of material may be incorporated into the cap design to provide protection against erosion currents at the site.

Consolidation. The total cap thickness should include a thickness to compensate for consolidation of the cap so that the minimum required cap thickness is maintained. Such consolidation occurs over a period of time following cap placement, but occurs only once. Therefore, the total cap thickness can be reduced due to consolidation without the need to nourish the cap. A prediction of the magnitude of the consolidation thickness is also important in interpreting monitoring data to differentiate between changes in cap thickness due to consolidation as opposed to those potentially due to erosion. Typically, sand does not consolidate; therefore, consolidation should only be considered for silt/clay caps.

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1 A table of factors for converting non-SI units of measurement to SI units is presented on page ix.

Placement variation. The sum of the cap design components for chemical isolation, bioturbation, consolidation, and erosion comprise the design cap thickness. However, the placement process may result in some unevenness of the cap thickness. This unevenness should be considered in calculation of the volume of capping material required. Monitoring will define the areas where minimum cap thickness is not achieved, and additional cap material may be required for those areas (Palermo, Randall, and Fredette; in preparation).

Cap effectiveness for chemical isolation

Dredging, dewatering, and transporting contaminated sediments to suitable upland disposal sites can be up to 100 times as expensive as capping open-water disposal sites. Despite extensive evidence that capped disposal mounds are stable, there are relatively few data available on the long-term effectiveness of capping (Sumeri and Romberg 1991). Results of a limited number of sediment chemistry profiles have been reported by Sumeri et al. (1994) for time frames extending up to 11 years following cap placement.

New England Division. In July 1990, the Disposal Area Monitoring System (DAMOS) Program conducted a study of the Stamford-New Haven, North (STNH-N) capped disposal mound at the Central Long Island Sound disposal site located 11 km south of New Haven Harbor, CN (Sumeri et al. 1994). This mound was created in 1979 during dredging of the Stamford and New Haven Harbors. Approximately 33,000 cu m of clean sand from outer New Haven Harbor was used for the cap, placed over approximately 26,000 cu m of contaminated mud dredged from Stamford Harbor.

Five sediment core samples were collected from the STNH-N mound for analyses of grain size and chemical contaminants. All of the cores penetrated the cap into the underlying contaminated material. Prior to analyses, each core was divided into 20-cm-long sections. Each section was homogenized and analyzed separately for three heavy metals (cadmium, copper, and zinc) and total petroleum hydrocarbons (TPH), which were known to be elevated in the contaminated Stamford sediments. Additionally, three cores were analyzed for polycyclic aromatic hydrocarbons, and one core was analyzed for polychlorinated biphenyls (PCBs) and pesticides.

The five cores all showed distinct visual transitions from the sand cap into the contaminated mud with the apparent zone of transition being less than 10 cm. Cap thickness ranged from 54 to 140 cm. For each of the five cores, heavy-metal levels were sharply higher within the mud layer, usually by one order of magnitude or more. Values within each layer generally agreed in magnitude with the predredging sampling results at the respective sources. Levels of TPH, also analyzed in all five cores, were one

to two orders of magnitude higher in the mud layer than in the sand layer of all five of the cores.

New York District. In 1980, 390,000 cu m of silt and clay were dredged from New York Harbor and placed at the Mud Dump Site, which is located in the Atlantic Ocean approximately 11 km east of New Jersey in the New York Bight apex (Sumeri et al. 1994). The material came from six projects with elevated but variable levels of heavy metals. This mound was then capped with 91,000 cu m of clean mud, followed by 938,000 cu m of sand.

Vibracore samples were taken from eight stations at the Mud Dump cap site in July 1983. All cores were analyzed to determine the thickness of the sand cap. Subsequently, the cores were subsampled at several discrete depths relative to the sand-mud interface. Each subsample was then analyzed for heavy metals (cadmium, copper, lead, and zinc), PCBs, and DDT and its metabolites.

Bokuniewicz (1989) reported that the vibracores taken through the capped mound 3.5 years after capping took place showed a sand layer with an average thickness of 1.1 m and a very sharp interface between the sand and the mud. Grain-size distribution in the cores showed that the sand-to-mud transition occurred over a distance of less than a few centimeters. Heavy-metal profiles in the vibracores of capped material showed that, in general, concentrations in the mud just below the sand-mud interface were an order of magnitude greater than the concentrations in the upper layers of the sand cap. In all cases, the concentrations in the interface region were less than concentrations 5 to 10 cm below the interface. Also, in most cases, PCB levels below the sand cap were at least a factor or two greater than concentrations in the sand cap. Pesticides were detected as trace-only levels in the interface and deeper samples.

Seattle District. In 1984 the Duwamish Waterway in Seattle was the initial northwest site for management of contaminated dredged material using capping (Sumeri et al. 1994). Approximately 840 cu m of contaminated fine-grained sediment was disposed in a borrow pit located in the West Waterway of the lower Duwamish River and capped with 3,200 cu m of clean sand dredged from the upper Duwamish Waterway.

The project was monitored during dredging, during disposal, and after disposal (at 6, 12, and 18 months and 5 years). The 5-year samples were three vibracores taken along the length of the project at the thickest part of the cap, as close as possible to the location of the samples taken 18 months after capping. Two cores were extracted within 5 ft of the 18-month core locations and the third within 15 ft. Prior to analyses, the cores were subsampled at several discrete depths relative to the sand-mud interface. Each subsample was then analyzed for total concentrations of copper, lead, zinc, and PCBs. These chemicals served as tracers to track potential movement of contaminants through the sand cap.

All postcapping sediment chemistry profiles showed similar results. The interface between the contaminated and cap sediments was observed to be sharp and relatively unmixed in all cores. In general, the concentrations of heavy metals and PCBs were at least an order of magnitude lower in the sand cap than in the contaminated material below. Chemistry profiles provided no indication of migration of contaminants into the sand cap. The 18-month and 5-year sediment chemistry sand-cap concentrations matched almost exactly.

Summary

Capping appears to offer a management option that will be effective for the long-term isolation of contaminated dredged material from the surrounding environment. Evidence on the ability to create caps and on the effectiveness of capping is rapidly increasing as follow-up surveys of such sites continue. Many of the questions about the effectiveness of caps to contain contaminants over long time periods can now be answered with greater certainty (Sumeri et al. 1994).

Design Guidance for Nearshore Berms

Nearshore-berm construction is a less expensive although complex alternative to conventional open-water placement that provides a beneficial use of dredged material. By accurate, controlled placement of dredged material, nearshore berms can be constructed to provide physical and biological benefits. Benefits include attenuation of wave energy, introduction of sediment into the littoral system, increased fisheries population and diversity, a substrata for oyster colonization, and cost reduction compared to more traditional disposal alternatives.

To ensure berm effectiveness, construction cannot be treated simply as a modification of conventional open-water disposal operations. The berm must be considered an engineered structure requiring a design template that can be verified and constructed, with provisions for periodic maintenance throughout the design life of the structure. Traditional equipment and procedures are not precluded from use in nearshore berm construction. Burke and Williams (1992); McLellan (1990); McLellan, Kraus, and Burke (1990); Burke and Allison (1992); Pollock and Allison (1993); and Pollock, Allison, and Williams (1993) draw on several completed nearshore-berm projects and offer comprehensive planning level guidance for nearshore berm design and construction.

Concepts

Nearshore berms are submerged high-relief mounds constructed parallel to shore and composed of clean predominately beach-quality dredged

material (McLellan, Kraus, and Burke 1990). Benefits can be classified as either direct or indirect. The direct benefit is widening of the beach by onshore movement of material from the berm. Indirect benefits are breaking of erosive waves, reduction of storm water-level setup on the beach face, and creation of an artificial storm bar that will reduce erosion by satisfying part of the demand for sediment to be moved offshore during storms. Nearshore berms are generally divided into two categories (feeder berms and stable berms), although Burke et al. (1991) have defined a third category (sacrificial berms).

Feeder berms. Feeder berms (Figure 4) are constructed of clean sand placed in relatively shallow water to enhance adjacent beaches and nearshore areas by mitigating erosive wave action and by providing additional material for the littoral system. If a berm is placed in sufficiently shallow water and with sufficiently high relief, the higher erosive waves accompanying storms will break on its seaward slope and crest. Broken waves of reduced height then re-form and progress toward the shore to break again with less energy. This energy-reducing mechanism provides an indirect benefit by reducing the erosional demand of storms for sediment to be moved offshore. Material removed from the berm and transported shoreward during periods of accretionary wave conditions supplements the beach profile by becoming part of the littoral system, contributing to the total volume of material available for beach recovery.

Stable berms. Stable berms (Figure 5) are intended to be permanent features constructed in deeper water outside the littoral environment. They may function to attract fish as well as reduce wave energy incident to the coast. Material from the berm is not expected to be transported to the littoral system and beach. Berms designed to be stable may be constructed of a wider range of materials and grain sizes than feeder berms. However, not all material will mound adequately or have the required stability to function as a stable berm. For some projects, material with low mounding potential has been intentionally spread over a large area using what is called thin-layer disposal. If a stable berm or mound consists of beach-quality sand, it can be used as a stock pile for future beach-nourishment projects.

Sacrificial berms. According to Burke, McLellan, and Clausner (1991), a third type of berm (sacrificial berm) may provide an additional nearshore alternative. This new type of berm placed in shallower waters would differ from a feeder berm in that it would be constructed of finer grain material, which would likely be carried offshore by waves, possibly nourishing the offshore profile and flattening its slope. This is in contrast to a feeder berm which may nourish the beach. The intent of the sacrificial berm would be to expend incident wave energy by preventing or reducing wave energy destined for that area from reaching the shore and potentially causing erosion. The sacrificial berm will expend wave energy, sparing the shoreline for as long as the berm remains in place. The life of the berm will be a function of the local wave climate after placement,

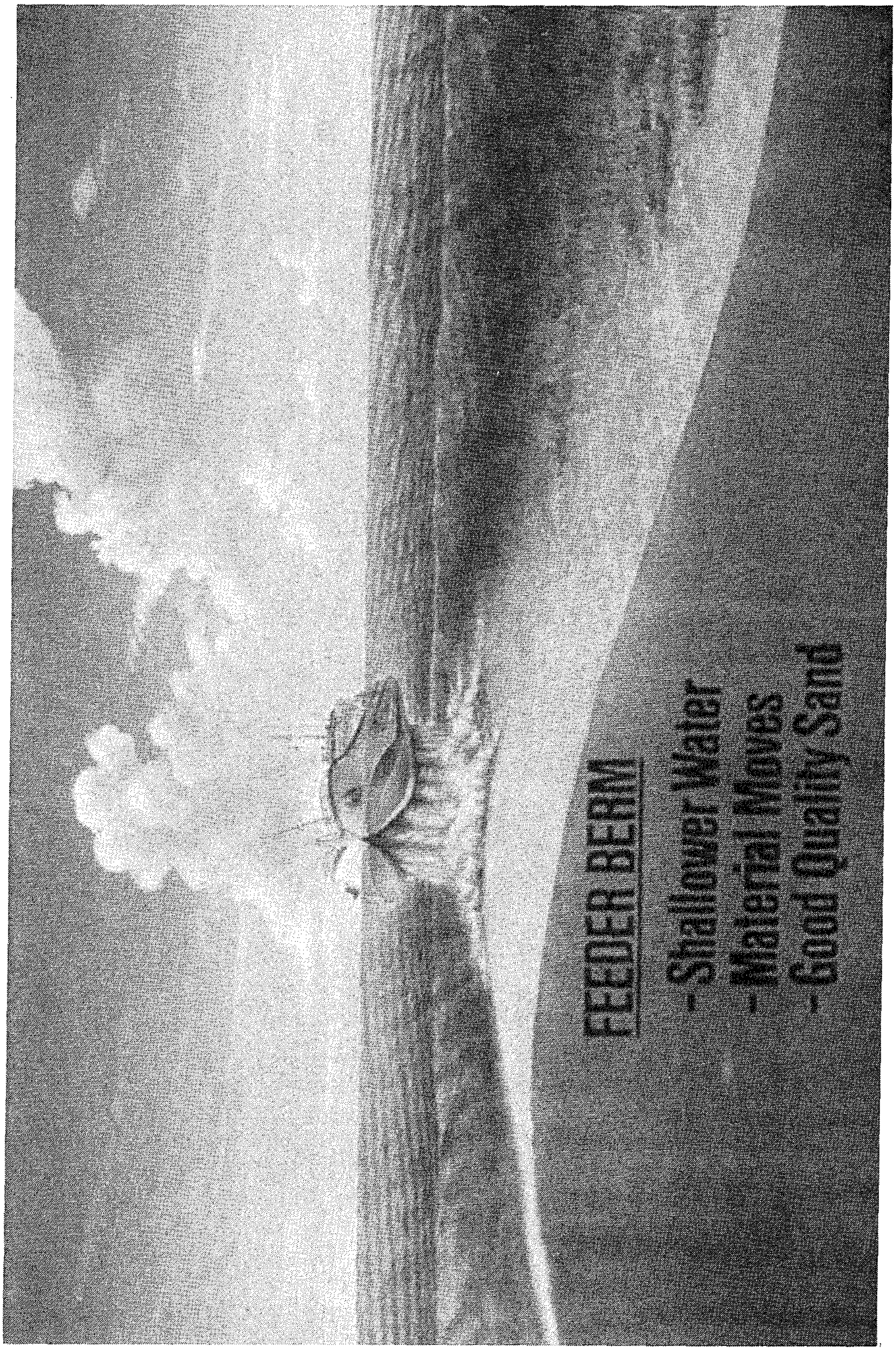

Figure 4. Schematic of feeder berm construction in nearshore zone

Figure 5. Schematic of stable berm construction in nearshore zone

grain size, type of material placed, and the dredging and placement technique used.

Berm design

Several steps must be followed to determine the potential for successful berm design and construction. These steps include evaluation of (a) quantity and quality of material to be dredged, (b) availability of suitable equipment, (c) local wave conditions, and (d) economics of berm construction and alternatives.

Material quality and quantity evaluations concern dredged sediment/beach compatibility, mounding properties, and available volume. If the dredged material grain size is compatible (i.e., similar or coarser grain size) with beach samples, a feeder berm can be constructed. The potential use of silt material and silt/sand mixtures is also being explored, the former in sacrificial berms and the latter with the expectation that the silts will winnow out and move offshore, leaving the sands to migrate onshore. If the material is not compatible with the native beach material but does have mounding potential, a stable berm can be considered; if the material is low-density fluid mud, mound construction is unfeasible. Conical-shaped mounds placed in the nearshore focus wave energy behind them and should be avoided. Berm length should be several times the average local wavelength, and the berm should be oriented parallel to the trend of the shoreline to minimize wave focusing and depth limitations of the dredge and to maximize extent of shoreline to be protected.

Local wave conditions determine the depth of placement for supplementing the supply of littoral material by feeder berms. Material to be placed at the design depth and crest elevation will require suitable equipment, usually a split-hull hopper dredge or barge. If the design calls for a feeder berm, it is optimally placed as close to shore as possible within constraints of safe navigation of the dredge or barge. Recent projects have shown that split-hull hopper dredges and barges are capable of constructing mounds at elevations above the loaded draft of the vessel. The main quantitative savings occur if haul distances are reduced by nearshore placement as compared to placement at previous disposal sites.

Berm length and end slope

The literature on nearshore berms indicates the potential for wave-focusing due to end effects at nearshore berm terminal points. End effects are due to wave shoaling, wave refraction, and bottom diffraction in regions of drastically variable topography, resulting in increased wave heights and altered wave direction in the lee of berm ends. These phenomena depend on the depth change at the berm and wave height, period, and direction. The length of the affected shoreline increases with increased end-slope steepness.

Nearshore berms should be of sufficient length to avoid focusing of waves at a location seaward of the shoreline. If a conical shape can cause localized erosion and an elongated oval shape has the potential to provide protection to the same region, the minimum length required of the feature's shore-parallel axis to achieve beneficial effects can be optimized. McLellan, Kraus, and Burke (1990) investigated nearshore berm projects that were being monitored and found that existing berms as short as 2.5 times the wavelength did not exhibit wave-focusing effects.

Numerical model study. Burke and Allison (1992) conducted a numerical analysis to minimize berm length and end slope dimensions to avoid focusing effects on the beach. The numerical model used in that study was the regional coastal processes wave (RCPWAVE) model. RCPWAVE estimates the characteristics of linear monochromatic waves as they propagate over arbitrary bathymetry. Aspects of linear wave theory represented in the governing equations used by RCPWAVE include refraction, shoaling, diffraction due to a very irregular bathymetry, and wave breaking. Finite-difference approximations of the governing equations are solved to predict wave propagation outside the surf zone.

Conditions assumed for the analysis were as follows. The equation for equilibrium beach profiles given by Dean (1991) and a grain size D_{50} of 0.2 mm were used for the profile on which the test berms for the RCPWAVE analysis would be placed. A generic berm configuration was created using the Silver Strand, CA, berm as a guide. The test berms were placed at the -18-ft mean lower low water (mllw) contours. A structure height of 6 ft was chosen to allow 12 ft of water over the crest, ensuring that hopper-dredge minimum-draft requirements could be met. The test crest lengths varied from 800 to 3,000 ft, with wave angles varying from ± 45 deg and wave periods varying from 4 to 20 sec. A 0-deg wave angle corresponded to a wave arriving perpendicular to the beach. The end slopes varied from 1V on 30H to 1V on 150H. Initial inshore slope was held constant at 1V on 25H, and initial offshore slope was held constant at 1V on 50H.

Numerical model results. Based on results of the numerical model study, steeper end slopes exhibited end effects across a narrower region parallel to the shoreline than did the milder end slopes, but the severity of the effects was greater than that of the milder slopes (higher wave heights in the lee of the berm ends). Longer period waves resulted in greater wave heights due to shoaling as depths decrease. Comparisons of all slopes indicated that gentler slopes optimize berm design by reducing end effects.

Wave heights in the lee of the berm parallel to the axis of the center of the berm were calculated at the -12-ft and -16-ft mllw contours. For the conditions tested, it was found that a berm 1,600 ft long or longer exhibited no end effects along the center axis of the berm at the -16-ft mllw contour. Berms of crest length equal to or greater than 2,000 ft displayed no wave focusing along the center axis at the -12-ft mllw contour.

To incorporate berm-relief change, additional berms with 8 and 16 ft of water over the crest were modeled. The same bathymetry grid was used. Even though the wave heights were greater on the shallower berms, wave focusing at the -16-ft mllw contour did not exist on berms 1,600 ft and longer for any berm reliefs.

Based on these numerical model evaluations, nearshore berms with 1V on 125H end slopes, 1V on 25H inshore slopes, 1V on 50H offshore slopes, and crest lengths equal or greater than 2,000 ft will not cause wave focusing for the wave conditions tested (i.e., nonbreaking waves).

Berm crest width

Another numerical model study was conducted by Pollock and Allison (1993) to ascertain the effect of berm crest width on the local wave climate. Minimum berm widths for maximum wave height reduction benefits were presented.

Numerical model study. The numerical model study used a version of the numerical model of the longshore current (NMLONG) that had been modified to calculate only wave transformation. Wave transformation includes shoaling, refraction, breaking with energy dissipation, and wave re-formation.

The same berm profiles used by Burke and Allison (1992) were utilized in this investigation. A 100-ft-wide berm crest was centered at the -18-ft mllw contour. Other berms were modeled by adding or removing a parallelogram section of the appropriate width from the seaward edge of the berm. Berm crest widths varying from 0 to 1,000 ft were tested. Still-water depths above the berm crest varied from 7 to 15 ft.

Waves were eliminated from testing if during the shoaling process the wave exceeded wave-breaking criteria prior to the -18-ft contour. Input waves were selected from waves with heights that varied from 1 to 12 ft and with periods that varied from 4 to 20 sec. All wave heights greater than 12 ft were eliminated because all broke before reaching the -18-ft contour. For the 12-ft wave height, only the 8- and 10-sec waves met the criteria. The 4-sec wave period would not support the 9- or 12-ft wave, and all 12-ft waves with wave periods above 10 sec broke before the -18-ft depth was reached. For the 9-ft input wave, all remaining wave periods met the criteria.

Numerical model results. Based on results of this numerical model study of the optimization of nearshore berm crest widths, greater wave attenuation in the lee of the structure was obtained by increasing the crest width up to an asymptotically limiting condition (Figure 6). The rate of increase in wave attenuation relative to berm crest width diminishes as the berm crest width increases. Steeper waves are affected more significantly by increases in crest widths than are less steep waves.

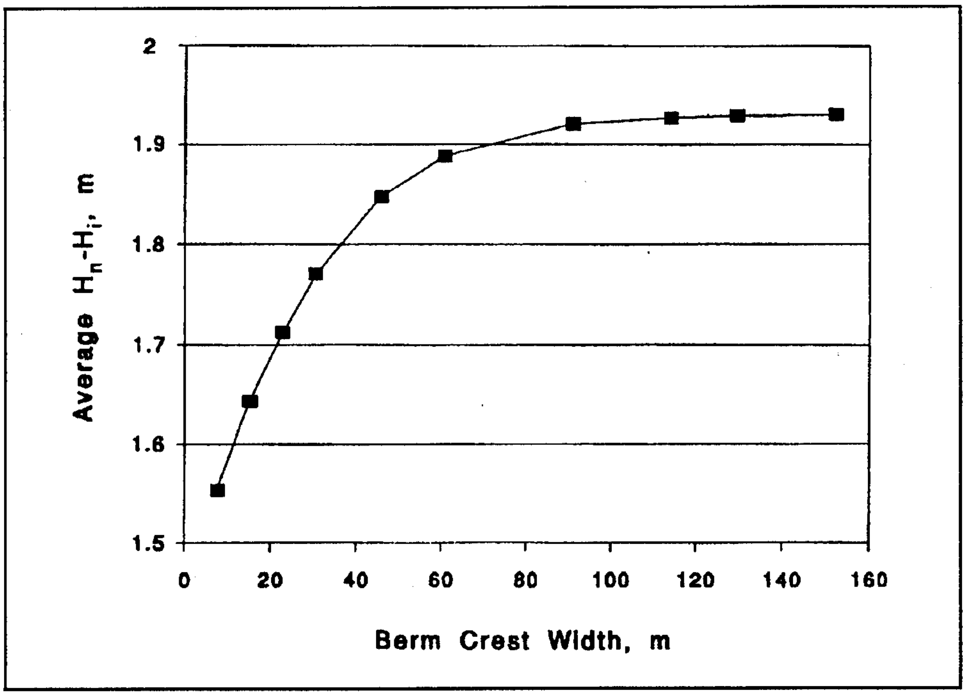

Figure 6. Effect of nearshore berm crest width on wave height

Using the numerical model NMLONG, wave-attenuation values were predicted for a suite of wave conditions and various berm widths placed in 18-ft water depths. From these results, reductions in wave height in the lee of the nearshore berm are associated with crest width increases. Additionally, for the test conditions of this study, significant wave-height reductions in the lee of the berm were achieved by increasing the nearshore berm crest width up to about 200 ft, but little or no change was realized for wider berm crests. Therefore, while berms with crest widths wider than 200 ft may be desirable from an operational, beach-building, or volumetric viewpoint, they may not provide significant additional wave-height-reduction benefits. However, berms may need to be constructed to a crest width greater than 200 ft because wave activity will re-form the berm and erode some of the material from the berm area. By constructing the berm to a greater crest width or by maintaining the berm crest width at or above 200 ft, maximum wave attenuation from the berm can be realized for a longer period of time.

Subsequent work by WES (Pollock, unpublished data) synthesizes information similar to Figure 6 for multiple nearshore berm geometries. This recent work (Figure 7) can be used to select appropriate crest widths relative to water depths and berm crest heights. This research provides additional tools for optimizing nearshore berm template design, and for estimation and evaluation of nearshore berm physical benefits of wave attenuation, mitigation of storm damages, and beach enhancement.

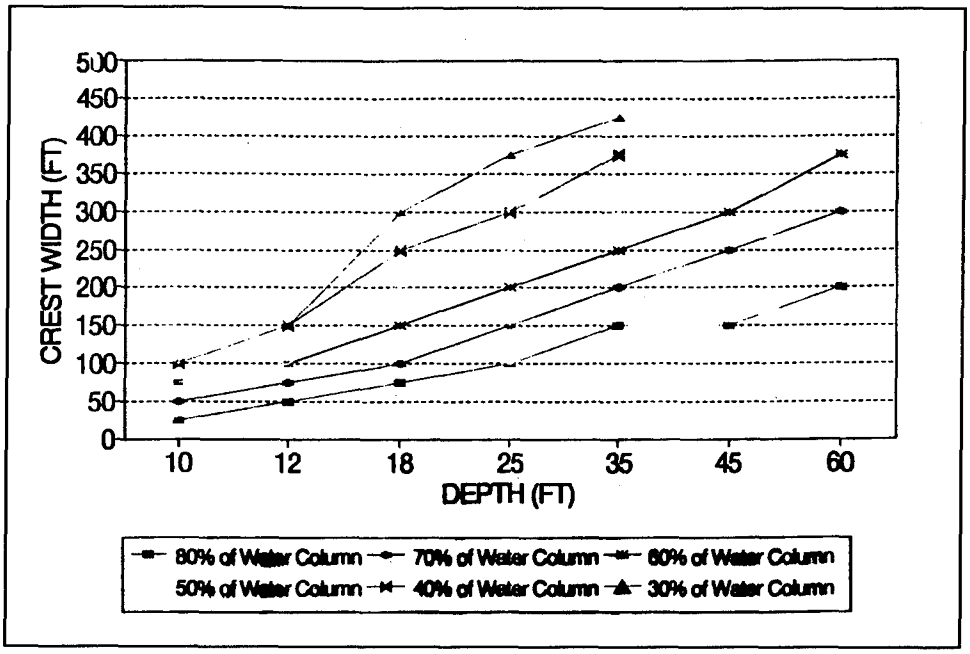

Figure 7. Nearshore berm crest width with maximum wave attenuation potential for a range of water depths and berm heights

3 Corps of Engineers Hopper Dredging, 1954-1994[1]

In 1954, the Office of the Chief of Engineers published *The Hopper Dredge: Its History, Development, and Operation.* This 400-page book, with its hard red-cloth cover, chronicled the history of the U.S. Army Corps of Engineers hopper-dredging program and described in detail the evolution and application of 100 years of hopper-dredge technical advances. This book, referred to as the "Red Book," became valuable to those in offices and onboard ships who were involved in planning and operating the Corps' seagoing hydraulic hopper-dredge fleet. It also became popular in Europe where it was used by dredge masters and others working to expand their knowledge and expertise in hopper dredging.

When the Red Book was written, the Corps owned and operated 20 hopper dredges. The Corps' fleet was spread throughout the coastal United States, with six hopper dredges on the west coast, eight on the east coast, three stationed on the Gulf coast, and three assigned to the Great Lakes. No private industry hopper dredges existed in the United States at that time. Indeed, the construction of 10 of these Corps hopper dredges between 1942 and 1949 indicated the U.S. government was gearing up to continue its traditional role of primary responsibility for the construction and maintenance of navigation channels in the United States.

By 1990 the face of hopper dredging in the United States had changed significantly. Policy changes within the Corps hopper-dredging program and external events such as new environmental regulations had resulted in a very different hopper-dredging program. The Corps hopper-dredge fleet had shrunk to four active dredges, all of them constructed since 1967: two on the west coast (*Yaquina* and *Essayons*); one on the east coast (*McFarland*); one on the Gulf Coast (*Wheeler*). For FY92, the Corps

1 Chapter 3 was extracted from Ogden Beeman and Associates, Inc. (in preparation).

dredged 22 million cu yd with those four dredges. Fifteen private industry hopper dredges vied for the remaining hopper dredging necessary to keep coastal and inland navigation channels at authorized depths. This meant 35.5 million cu yd of new work and maintenance dredging was performed by private industry.

The purpose of *Corps of Engineers Hopper Dredging, 1954-1994* (Ogden Beeman and Associates, Inc. (in preparation)) is to describe major events in the Corps of Engineers hopper-dredging program since publication of the Red Book. Hopper-dredge activities, programs, and policies are addressed, as well as operating characteristics and technologies pertaining to hopper dredging. Additionally, each of the four currently active Corps hopper dredges is discussed in detail. The following text was extracted exclusively from that publication.

The Hopper Dredge

A hydraulic hopper dredge (Figure 8), or trailing suction dredge, is a self-propelled seagoing ship with sections of its hull compartmented into one or more hoppers. It is normally configured with two drag arms, one on each side of the dredge. During dredging, bottom sediments are sucked into the drag arm assemblage by hydraulic pumps and deposited into the dredge's hoppers. The material enters the hoppers in slurry form and settles to the bottom as excess water flows over the top of the hoppers. Once the hoppers are full, the drag arms are lifted,and the dredge sails to the disposal area where the material is usually dumped through doors located at the bottom of the hoppers. In some instances, agitation dredging is conducted where the material is suspended and allowed to be carried away by natural currents.

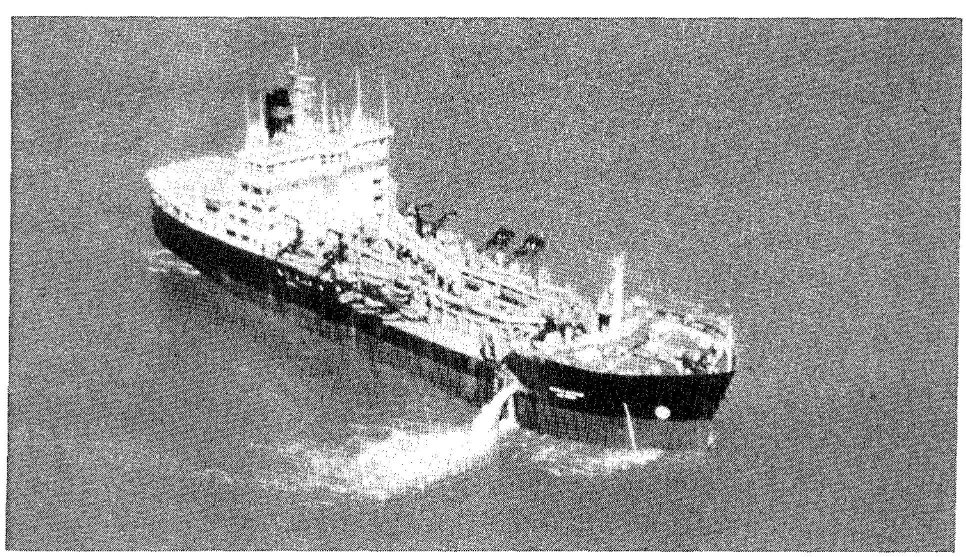

Figure 8. Corps of Engineers hopper dredge

Hopper dredges may range from 150 ft to 550 ft in length. As ships, hopper dredges are subject to American Bureau of Shipping classification and must comply with strict licensing requirements regarding construction, maintenance, and operation. Hopper-dredge personnel live and work onboard ship; modern hopper dredges are fully equipped with living quarters, galleys, recreation rooms, and other amenities.

Application

Hopper dredges are used mainly for dredging in wave-exposed harbors and shipping channels where traffic and operating conditions preclude the use of more stationary dredges and their attendant pipelines or dump scows. They are also effective working offshore and in entrances where sea and weather conditions preclude the use of extensive dredge pipe. Most modern hopper dredges are capable of operating, albeit at reduced efficiencies, in ocean swell up to 12 ft high. They are important for accessing disposal areas many miles distant from the dredging areas. In addition, hopper dredges are self-propelled, which enables them to deploy quickly with little or no attendant plant.

Materials excavated by hopper dredges cover a wide range of types, but the hopper dredge is most effective in the removal of unconsolidated gravel, sand, and silt (materials that are common in rivers, estuaries, and harbors). They are not as effective in dredging clay, rock, or other consolidated materials.

Disposal methods

While the traditional dredged-material disposal method is bottom dumping of material through the hopper bottom doors, other disposal methods have been developed to address specific project requirements, operating conditions, and/or environmental considerations. In 1950 the two types of hopper-dredging disposal were bottom dump and agitation. In the 1960s, the Corps undertook an aggressive program to develop direct pump-out capabilities on hopper dredges for beach nourishment and other purposes. Direct pump-out and sidecasting were added as disposal options. In addition, the Corps developed the special purpose split-hull barge, *Currituck*, which was designed to work shallow east coast harbors. The *Currituck*, which operates similarly to a hopper dredge, deposits material directly in the nearshore beach zone by moving close to shore and splitting its hull.

Hopper-Dredge Activities

Hopper-dredging activities of the Corps of Engineers fall into one of three distinct categories: (a) navigation channel construction and maintenance, (b) military defense activities, and (c) emergency operations.

Navigation channel construction and maintenance

The Corps hopper-dredge fleet has historically been used to develop and maintain navigation channels and harbors along the U.S. coastline and within the Great Lakes. The Corps' role in harbor and channel development evolved cautiously during the 19th century; private and state interests were generally the initiators of waterway improvements although the federal government occasionally appropriated funds or provided assistance through land grants and stock purchases.

One of the projects receiving federal funds in the mid-1850s was Charleston Harbor, SC, and one of the funded items was leasing the hopper dredge *General Moultrie*. The *General Moultrie* was a casualty of the Civil War, but U.S. rivers and harbors benefitted from an increased federal interest following the war as Congress significantly increased authorizations for river and harbor improvements. By 1900, the Corps had constructed six hopper dredges that were working on the Gulf, east, and west coasts. In 1906 the only remaining industry firm operating hopper dredges went out of business, and the Corps was left as the sole owner and operator of self-propelled hopper dredges in the United States until 1977. By 1924 the Corps had built or acquired a total of 40 hopper dredges, 6 of which were still operating in 1950. These 6 were supplemented with 14 newer hopper dredges, for a total Corps fleet of 20 hopper dredges in 1950. Corps hopper-dredge fleet District assignments for navigation-channel construction and maintenance at 10-year intervals for the period 1951 through 1991 are shown in Table 1.

Military defense activities

World War II. The need for adequate channel depths to accommodate naval vessel and other activities during wartime necessitates dredging. The Corps hopper-dredge fleet is called upon occasionally by the Defense Department to assist with military actions during wartime. During World War II, 14 U.S. government hopper dredges were assigned to the European and Pacific theaters. The dredges *Comstock, Harding, Hoffman, Marshall, Minqual,* and *Rossell* all served in the European theater. The *Barth, Davison, Hains, Hyde, Kingman, Lyman, MacKenzie,* and *Pacific* were assigned to military duties in the Pacific theater. The dredges were subject to enemy fire as well as unusual weather and dredging conditions.

Korean conflict. During the Korean conflict, the *Davison* was employed to clean out the Inchon tidal basin after retreating United Nations' forces damaged the lock gates at the Port of Inchon early in the conflict. The Port of Inchon is a major deepwater port on the western coast of Korea where daily tidal variations can be up to 30 ft. This port was of strategic importance for the landing of supplies and troops, and the *Davison* cleared the harbor of sediment accumulation.

Table 1
Corps Hopper-Dredge Assignments

Region/District	Year of Inventory and Hopper Dredge Name				
	1951	1961	1971	1981	1991
Great Lakes					
Buffalo	*Hoffman*	*Markham*	*Markham*	*Markham*	
	Savannah	*Hoffman*	*Hoffman*	*Hoffman*	
	Taylor	*Lyman*	*Lyman*	*Lyman*	
Milwaukee	*Haines*				
Detroit		*Haines*	*Haines*	*Haines*	
East Coast					
New York	*Essayons*	*Essayons*			
	Goethals				
Philadelphia	*Harding*	*Comber*	*Comber*	*Comber*	*McFarland*
	Rossell	*Goethals*	*Goethals*	*Goethals*	
	New Orleans				
Norfolk	*Comber*				
Savannah	*Gerig*				
Jacksonville	*Hyde*	*Hyde*	*Hyde*	*McFarland*	
	Lyman	*Gerig*	*Gerig*		
Gulf Coast					
New Orleans	*Langfitt*	*Langfitt*	*Langfitt*	*Langfitt*	*Wheeler*
Galveston	*Biddle*	*MacKenzie*	*MacKenzie*		
			McFarland		
West Coast					
San Francisco	*Davison*				
Portland	*MacKenzie*	*Biddle*	*Biddle*	*Biddle*	*Essayons*
	Michie	*Davison*	*Davison*	*Pacific*	*Yaquina*
	Pacific	*Harding*	*Harding*	*Yaquina*	
		Pacific	*Pacific*		
Seattle	*Kingman*				

Vietnam war. The Vietnam war brought another engagement of U.S. hopper dredges to overseas military action. Only two southern ports (Saigon and Cam Rahn Bay) were capable of accommodating deep-draft vessels prior to the buildup of military forces in Vietnam in 1965. To support U.S. assistance during the war, the ports of Saigon, Da Nang, and Cam Rahn Bay were turned into major logistical bases, and minor support bases were developed at six other areas. The effort required the world's largest dredging operation to that time: 23 cutterhead, hopper, and mechanical dredges were employed in 1969 to clear and construct harbors primarily in the Mekong delta area.

The Vietnamese Ministry of Public Works, Transport, and Communications contributed nine dredges. A joint venture of Raymond International and Morrison-Knudsen, Brown, Root, and Jones brought 10 dredges to the effort under contract to the Naval Facilities Engineering Command. A third fleet was made up of four training dredges operated by the Republic of China's Retired Servicemen's Engineering Agency under contract to the U.S. Agency for International Development. Corps of Engineers hopper dredges *Davison* and *Hyde* joined this effort in 1966, and in 1967 the Corps' sidecaster *Schweizer* began work in Vietnam. The *Hyde* was damaged extensively after two explosives detonated against the hull; however, the crew saved the vessel from sinking and had it operating again in less than 72 hr. The Corps of Engineers dredging operation in Vietnam suffered no loss of life.

Post-Vietnam. Corps hopper dredges have not had active defense assignments since Vietnam. During the Persian Gulf War in 1991, there was discussion about deploying Corps hopper dredges to assist with navigation maintenance and oil-spill remediation, but no dredges were actually sent to the Persian Gulf.

Public Law 95-269, enacted April 26, 1978, directed the Chief of Engineers "...to undertake a study to determine the minimum federally-owned fleet required to perform emergency and national defense work." This action was followed in 1987 by a U.S. Army Audit Agency report that recommended "...reassessing the composition of the minimum fleet to include current defense requirements and private industry capability..." As a result of the 1987 recommendation, the Corps agreed to reassess the minimum dredge fleet every 5 years. The Corps' military dredging history and ongoing efforts to evaluate potential dredge requirements for military actions demonstrate the historic and ongoing relationship Corps' dredges have with military activities.

Emergency operations

Corps hopper dredges may be mobilized in response to emergency situations. The Corps defines emergency dredging as "dredging performed when unexpected situations require an immediate and effective response in order to protect lives and property, or to maintain or restore channel

dimensions, thereby minimizing disruption of essential waterborne commerce and the economic livelihood of a region."

There are two primary authorities under which the Corps responds: (a) Section 3 of the River and Harbor Act of 1945 provided continuing authority for limited emergency clearing of navigation channels, and (b) Public Law 99, passed in 1955, amended previous flood-control acts to provide for an emergency fund for flood-emergency preparation, flood fighting, and rescue operations. The Corps generally refers to its emergency dredging as PL-99 activities, and records yardage and costs for PL-99 work separately from other work since it is covered by a different funding source. While there has been no PL-99 work performed by Corps hopper dredges in the recent past, contributions are made by the dredges during flood emergencies under normal operations and maintenance budgets. Two emergency situations have demanded special attention from Corps hopper dredges in recent years: (a) the Mt. St. Helens, WA, volcano eruption, and (b) the *Exxon Valdez*, AK, oil spill.

Mt. St. Helens eruption. The Mt. St. Helens volcano erupted on May 18, 1980. The mountain, located in southeastern Washington state, spewed 4.0 billion cu yd of ash and mudflow into the atmosphere and river basins. Much of the mudflow settled in the Toutle River, a tributary to the Cowlitz River, which flows into the Columbia River at approximately Columbia River Mile 68, near Longview, WA. The Columbia River provides a 600-ft-wide by 40-ft-deep navigation channel from the Pacific Ocean to Portland, OR.

It took the mudflow less than 24 hr to travel approximately 40 miles through the Toutle and Cowlitz systems to the Columbia. The U.S. Coast Guard closed the river to navigation at Longview on May 19, stranding 31 ships at ports upriver and 50 ships at points along the lower river. The Corps hopper dredge *Biddle* was working at the mouth of the Columbia River. It was ordered to proceed with caution to the closed river section and begin emergency dredging. The Portland District's two other hopper dredges, the *Harding* and *Pacific*, were mobilized from Eureka, CA, and Coos Bay, OR, respectively, to join the emergency dredging operations. The Columbia River draft in this region had been reduced from 40 ft to 14 ft within a few hours. A total of 19.65 million cu yd were dredged before the effort was completed, 20 percent by Corps hopper dredges.

***Exxon Valdez* oil spill.** The *Exxon Valdez* hit a reef off Bligh Island in Prince William Sound, AK, on March 24, 1989. The 987-ft-long, 166-ft-wide, 88-ft-draft vessel was outbound loaded to near capacity with 1.2 million barrels of Prudhoe Bay north slope crude oil. On March 25, Exxon announced that 260,000 barrels of crude oil had been spilled into the sound.

Initial emergency response efforts were hampered by ill-prepared ground crews, unorganized equipment, and high winds that grounded aircraft, hampered boat operations, and emulsified the oil. By March 26

only about 3,000 barrels had been skimmed off the water, and the oil slick had grown to over 100 sq miles. It was recognized the Corps would be an important player due to its contracting capabilities, expanding environmental mission, and varied resources. Discussions were initiated regarding the feasibility of using Corps hopper dredges in the oil-spill cleanup, and dredges *Yaquina* and *Essayons* were deployed to Alaska on April 12 and 17, respectively. As oil skimmers, they were inexperienced and unproven.

During the first day's operation, the *Yaquina*'s crew tried various configurations of auxiliary pumps to pump the material directly into the hoppers, but the pumps could not move the thick oil and debris. By mid-afternoon, the only alternative left was to use the dredge pumps. No one knew how the oil mixture would affect the dredge pumps, the drag arms, or other parts of the dredge. The dragheads were inverted (Figure 9) and brought up underneath the oil (Figure 10). During the first 15 min of pumping, approximately 500 barrels of oil were collected. The most critical part of the operation was placement of the draghead in relation to the thin layer of oil on the water surface. (The oil layer was spreading and decreasing in thickness with each passing day.) The operator had to get the inverted draghead close enough to the surface from underneath the layer of oil to get more oil than water, but had to avoid breaking the surface and pumping air to keep its prime.

The experience of the *Yaquina* was valuable to the *Essayons* when it started operations. But the *Essayons* was working in less protected waters with higher wave climates and controlling the draghead's proximity to the surface was more difficult. On May 8 the *Essayons* captured 200 barrels of oil in 5-ft seas; by May 10 a combined total of 5,016 barrels of oil had been collected by the two dredges.

By mid-May the main efforts of the cleanup had shifted to shoreline operations and the *Yaquina* was sent to Seward for cleaning prior to its return to Portland. The *Essayons*, which had spent much of its Alaskan time serving as a collection barge for contaminated materials from the shoreline cleanup, arrived in Seward on May 31 for cleaning. The cleaning of both dredges was laborious and time consuming, but the cleaning operation was especially difficult for the *Essayons* because of the variety of materials that had been placed in the hoppers while it served as a collection barge. The *Yaquina* returned to Portland on June 15 and the *Essayons* returned on July 24.

Engineering and Design

The support structure for the Corps hopper-dredging program is extensive and varied. Support includes specific programs that have been developed solely for the purpose of improving hopper dredges.

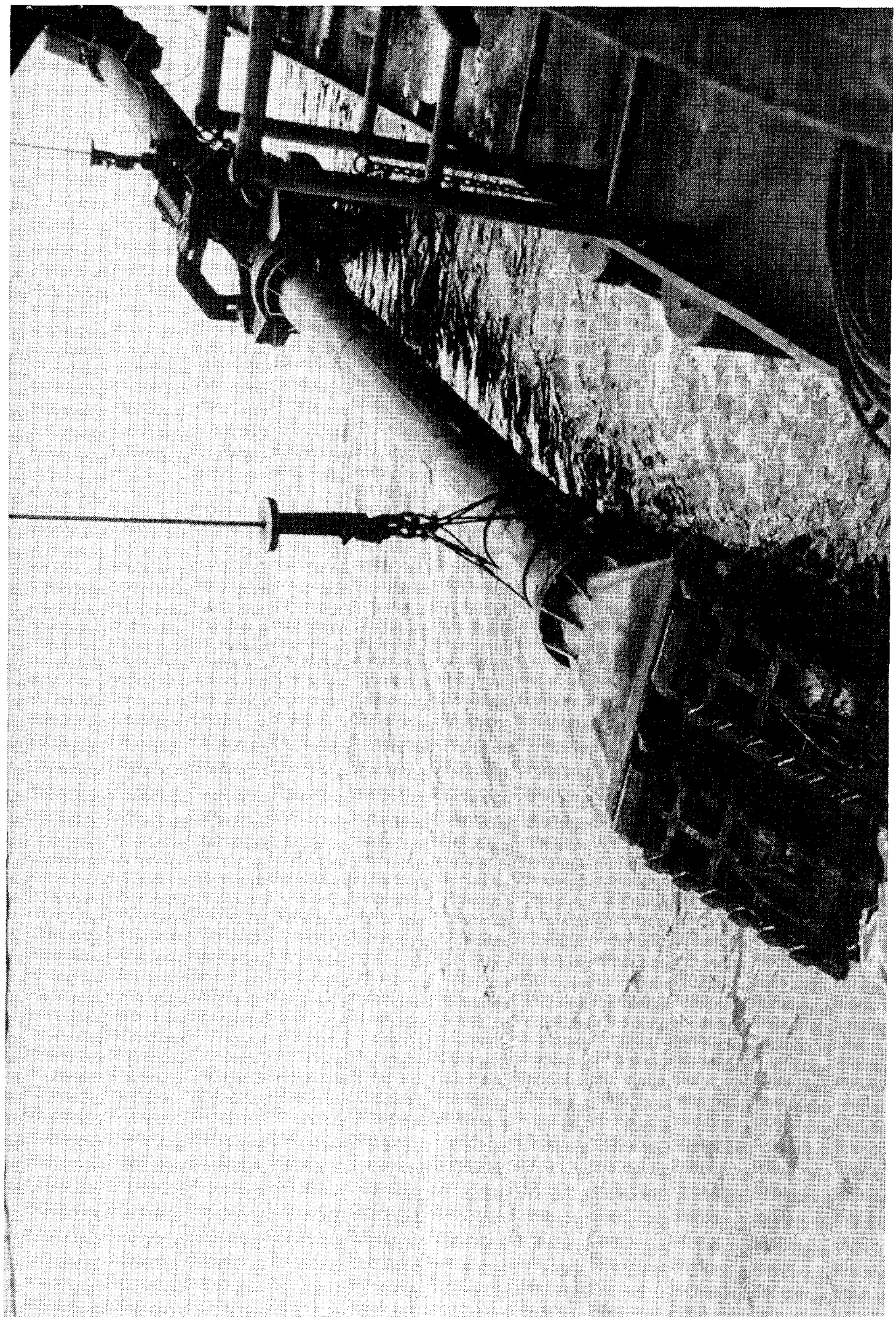

Figure 9. Hopper dredge *Yaquina* draghead turned upside down to collect *Exxon Valdez* oil spill

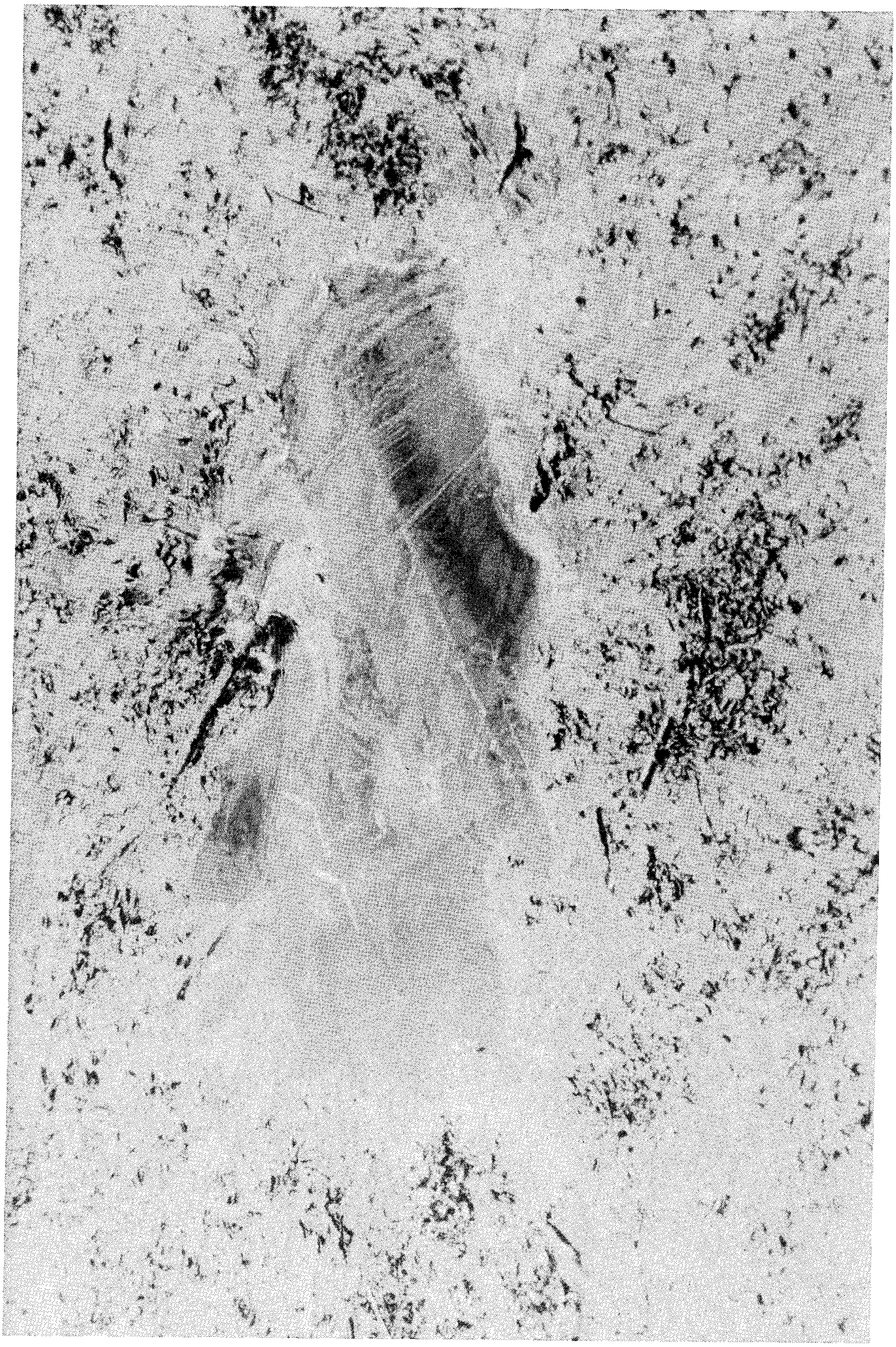

Figure 10. Hopper dredge *Yaquina* draghead positioned upside down below *Exxon Valdez* oil spill

Marine Engineering Board

The Marine Engineering Board was initially established by the Chief of Engineers in 1944 under the title Hopper Dredge Board. Its designated duties at that time were to "review all plans for any hopper dredge construction and pass on matters of policy and general features of design." Three years later the responsibilities of the Board were broadened and "will recommend policies and general features of design for hopper dredge construction, will review all plans for new hopper dredges and all major modifications of existing hopper dredges, and will perform such other functions in connection with hopper dredges as may be assigned by the Assistant Chief of Engineers for Civil Works."

Board members have consistently been civilian engineers who have management and technical experience in the design, construction, operation, and repair of marine plant. In 1963 the name was changed to Dredge Board, and in 1974 it was again changed to its present designation of Marine Engineering Board. The Board's mandate was broadened to encompass nonhopper-dredge activities, and through the years membership on the Board has expanded to include representatives from diversified Corps Districts and Divisions. Ex officio members were also designated to participate in an advisory (nonvoting) capacity.

In 1990 the Board's mandate was revised and set forth in a new Engineering Regulation, ER 15-2-6 (U.S. Army Corps of Engineers 1990). The Board's primary functions are to:

a. Establish fundamental principles for the design, construction, and operation of marine plants.

b. Recommend policies and major design features for new construction, and major alterations to marine plants.

c. Review requests for waivers to standard designs.

d. Review innovative design concepts and objectives for major items of floating plants.

e. Recommend policies for acquisition, replacement, or rehabilitation of major items of floating plants.

f. Review requests for waivers to Major Subordinate Commands/ District Commands design of major items of floating plant.

g. Perform program review and establish project priorities for the Marine Design Center.

h. Perform other functions in connection with dredges and other marine plant, dredging techniques, work practices, and operational procedures as assigned by the Director of Civil Works.

Marine Design Center

The Marine Design Center located in the Philadelphia District is the marine plant design center for the Corps of Engineers. Originally established in 1908 as the Marine Design Division, it has played a major role in the development of hopper-dredge plant and the advancement of technology pertinent to hopper dredging and disposal. During World War II, the Division shouldered a large share of the design and construction of floating plants of all kinds, including tugboats, towboats, oil and water barges, and floating cranes and derricks. Following World War II, the Division designed and commissioned construction of five new hopper dredges by 1949, including the *Comber, Biddle, Gerig, Langfitt,* and *Essayons.*

Major hopper-dredge projects for the Marine Design Division during the 1950s included the hopper dredge *Markham,* which was specifically designed for operation on the Great Lakes. During this period, the Corps was following a nonexpansion policy with its hopper-dredge fleet: new dredges were being built as replacements for existing equipment, but the Corps was not expanding its holdings. This policy was due in part to the fact that the newer dredges were more efficient, had greater capacities, higher speeds, and better maneuverability. Therefore, much of the Division's work in the hopper-dredge area focused on modifying the existing fleet to meet project requirements.

By the 1960s, there were 15 hopper dredges in the Corps fleet. Nonhopper-dredge-related work dominated activities at the Division, although it undertook design and construction of the hopper dredge *McFarland* and designed conversions of the hopper dredges *Comber, Goethals, Lyman, Hains,* and *Hoffman* to direct pump-out capability. The *McFarland* was designed for work along the coast of the Gulf of Mexico. It was capable of discharging dredged material by any one of three systems: (a) bottom dumping through hopper doors; (b) pumping through a connection to a shore pipeline directly into an upland disposal area; or (c) pumping through a boom-supported discharge pipe directly into adjacent waters.

During the 1970s, the Marine Design Division designed and accomplished the repowering of the hopper dredge *Pacific* and moved forward with the design and construction of three new hopper dredges: the *Yaquina, Wheeler,* and *Essayons.* The name of the Marine Design Division was changed in the 1980s to the Marine Design Center. During the remainder of the 1980s and through the early 1990s, the Marine Design Center continued to design and construct new marine plants, but no new hopper dredges were to come on-line during the period. The Center continues to provide design for rehabilitation and new technology for the existing fleet.

Improvement Program

The hopper dredge improvement program was initiated in 1957 to aid the Corps in increasing operational effectiveness of hopper dredges and thus reduce related unit costs through development of improved procedures, designs, and devices. The Marine Design Division conducted the developmental tasks. The program continued through the early 1970s. It provided opportunities for Districts to research and solve problems specific to their own requirements and also provided opportunities for some updating of the Corps' fleet. Some of this research was integrated into the design of new Corps hopper dredges that were constructed in the 1970s. Thirteen separate research projects were conducted:

a. Develop design criteria for dredge pumps suitable for pumping viscous water-solids mixtures.

b. Develop distribution system to provide better intermixing of material, uniform loading, increased retention of fine grains, and individual hopper discharge control.

c. Evaluate electronic positioning systems for hopper dredges and survey boats.

d. Determine suitability of impressed current cathodic protection systems for protecting hopper-dredge hulls from corrosion.

e. Improve existing gas-removal systems and develop more effective gas-removal techniques.

f. Develop and test improved instrumentation to measure and monitor dredging processes; provide techniques for more efficient control of the dredging processes.

g. Develop improved dragheads to attain greater rate of intake of solids, especially consolidated fine sand and viscous silt mixtures.

h. Develop, test, and evaluate flexible draghead pipe coupling to replace ball joints in suction assemblages of hopper dredges.

i. Evaluation of range lights and targets for hopper-dredge operations.

j. Evaluate and test 4- and 10-in. jetting systems to increase productivity and reduce dredging costs.

k. Evaluate effectiveness of hopper dredges for beach nourishment, including pump-out facilities.

l. Evaluation of precision profiler echo sounder and its suitability for Corps work.

k. Test and evaluate effectiveness of chemical coagulants added to slurry to aid settling in the hopper bin.

Industry's Capability to Meet National Dredging Requirements

By the early 1970s, the existing Corps hopper-dredge fleet was in need of modernization. Of the fleet of 16 Corps hopper dredges, 14 had been constructed and put in service prior to 1949. Petitions to Congress from the Corps for additional funds to update the fleet had been unsuccessful for about 10 years. Congress was mindful that private dredging contractors in the United States believed they were capable of supplying hopper dredging in addition to their established capability in pipeline and mechanical dredging. The Corps had been the sole owner and operator of hopper dredges in the United States since 1906. In 1973, Congress directed the Corps to conduct an in-depth national dredging study to evaluate national dredging needs, survey the physical condition of both the Corps and private fleets, and assess the government's bidding procedures. Congress also specified that the study "must include consultation with the dredging industry, including their views and recommendations on various alternatives for meeting the national dredging requirements."

National dredging study and Industry Capability Program

After identifying the desired scope of the study and a competitive national contractor-selection process, a management consulting firm was hired to conduct the national dredging study. The study process was extensive. Corps Districts provided information on operations and costs for their 98 hopper, pipeline, and mechanical dredges. Industry was polled for their experience with operations, costs, profitability, and other factors.

As a result of the national dredging study, Congress initiated an industry capability program to place industry dredges in competition with government hopper dredges on selected dredging projects for a "testing of the market." The Corps and private industry contractors essentially bid on the same projects from the same bid documents, plans, and specifications. The Corps prepared a hired labor estimate for each project and contractors were told which hopper dredge and disposal method were being used for the estimate. Allowance for profit was not included in the Corps estimate. The job was awarded to an industry contractor if its bid was not more than 125 percent of the hired labor estimate. The Corps was awarded the project if industry bids all exceeded 125 percent of the hired labor estimate. Industry contractors, anticipating that hopper-dredge work would become available, had proceeded with design and construction of hopper dredges.

As the testing of the market program proceeded, Congress also proceeded with legislation to ensure industry's participation in dredging projects. The Corps became a strong supporter of private industry's expansion into hopper dredging and was anxious to increase American capability, in part to assist foreign countries with their redevelopment efforts. Port-operating interests, however, were concerned that increased industry participation in dredging projects would increase costs, causing projects to be delayed or eliminated. The alliance of private industry and the Corps prevailed, and Public Law (PL) 95-269 became effective in 1978. PL 95-269 applies to all dredge types and remains today as landmark legislation for the dredging industry. Key provisions include:

a. The Corps shall have dredging and related work done by contract if it is determined that private industry has the capability to do such work at reasonable prices and in a timely manner.

b. The Federally owned fleet shall be reduced in an orderly manner by retirement of plant. The Corps shall retain a minimum federally owned fleet required to carry out emergency and national defense work.

c. Work necessary to keep the minimum fleet operational can be set aside from those projects to be bid by industry.

d. The Secretary of the Army shall submit to Congress within 2 years a minimum fleet study that defines the minimum fleet dredges.

e. The government, when estimating its dredging costs, shall consider depreciation, supervision, overhead expenses, interest on capital investment, and other appropriate charges.

When the industry capability program ended in fiscal year 1981 (FY81), 149 dredging jobs had been advertised and 83 of them awarded to industry. Of 93 total hopper-dredge jobs, 50 had gone to industry. Eight hopper dredges had been acquired by industry and another two were online. The industry capability program had demonstrated that industry could respond to hopper-dredging demand.

Minimum dredge fleet

PL 95-269 required the establishment of a minimum fleet that includes both hopper and nonhopper dredges to meet emergency and defense preparedness. The law states:

> As private industry demonstrates its capability...the federally owned fleet shall be reduced in an orderly manner, as determined by the Secretary, by retirement of plant. To carry out emergency and national defense work the Secretary shall retain only the minimum federally owned fleet capable of performing

> such work and he may exempt from the provisions of this section such amount of work as he determines to be reasonably necessary to keep such fleet fully operational, as determined by the Secretary, after the minimum fleet requirements have been determined. Notwithstanding the preceding sentence, in carrying out the reduction of the federally owned fleet, the Secretary may retain so much of the federally owned fleet as he determines necessary, for so long as he determines necessary, to insure the capability of the Federal government and private industry together to carry out projects for improvements of rivers and harbors.

The Corps began to retire its existing hopper fleet before results of the minimum fleet study, mandated by PL 95-269, were complete. The Corps also began to build new dredges to meet the requirement for "technologically modern and efficient standards, including replacement as necessary" as stated in PL 95-269.

Results of the minimum fleet study, which was performed by the Corps, were available in 1978. The study recommended a Corps minimum fleet of eight hopper dredges: two each for the gulf and Great Lakes and the east and west coasts of the United States. Industry, faced with a much decreased workload than that which had been predicted by the national dredging study, strongly opposed an eight-dredge Corps hopper fleet. Industry was concerned that their new equipment would stand idle. Industry indicated they desired a Corps fleet in the range of two to five vessels. On the other hand, the American Association of Port Authorities adopted a position recommending ten Corps hopper dredges rather than just eight.

In 1979 the minimum-fleet recommendation for eight Corps hopper dredges was forwarded to the Assistant Secretary of the Army for Civil Works (ASACW). The Office of Management and Budget requested that additional information on justification of an eight-hopper-dredge minimum fleet be provided. This Corps reassessment reaffirmed the initial conclusion that an eight-hopper-dredge fleet was required.

By the end of FY81, the Corps had retired five hopper dredges: the *Essayons, Gerig, Davison, Hyde,* and *Harding*. The new small-class *Yaquina* was placed in service in 1981. As discussions regarding the minimum fleet continued during 1982, four more Corps hopper dredges were retired: the *Biddle, Lyman, Langfitt,* and *Goethals*. The new large-class hopper dredge *Wheeler* began its tenure when placed in service in 1982.

The Corps made a final appeal to the ASACW in 1982 to maintain a Corps minimum fleet of eight hopper dredges. However, the political climate could not support the plan. The pressure from industry to increase industry's share of the dredging load and the overall pressure to reduce costs were major factors that resulted in a 1983 ASACW decision which affirmed that the Corps minimum fleet would consist of four hopper

dredges and six nonhopper dredges. In addition, the Corps would initiate the Corps of Engineers' reserve fleet (CERF) in a partnership with industry to augment dredging capability for national defense and emergency purposes.

The CERF program proposed a guaranteed response by private industry to emergency and defense situations. The Corps' four hopper dredge minimum fleet and contribution to CERF was to consist of a new *Essayons*, the *Yaquina*, the *Wheeler*, and the *McFarland* (which had been brought on-line in 1967). By 1985, 15 private-industry hopper dredges were part of the CERF in addition to the four Corps hopper dredges.

In 1987 the U.S. Army Audit Agency recommended a reassessment of the minimum fleet composition to "include current defense requirements and private industry capability." The Corps agreed to reassess the fleet every 5 years. The Chief of Engineers commissioned the U.S. Army Engineers Study Center (ESC) to initiate a related task in 1990 for an assessment of two specific issues: (a) the Corps dredge fleet necessary to meet navigation, emergency, and military requirements, and (b) independently, the military need for a minimum fleet.

The ESC reports were released in 1991. The analyses of overall requirements were based on 1988 and 1989 dredging data only, constraining the investigation's scope. Essentially, ESC concluded that hopper-dredging capability was definitely needed in the United States, but it should not necessarily be the Corps' responsibility. The second investigation concluded that existing military needs in themselves did not require a Corps minimum fleet.

Debate and discussion regarding the Corps' minimum hopper and nonhopper dredge fleets continue into the 1990s. At present, the Corps' minimum hopper-dredge fleet remains at four hopper dredges that are supplemented through the CERF program with industry's hopper dredges.

Engineer Manual 1125-2-312, "Manual of Instructions for Hopper/Sidecasting Dredge Operations and Standard Operating Procedures"

A new EM was developed to replace the existing EM 1125-2-312 (U.S. Army Corps of Engineers 1994). The new EM provides guidance on current operating and reporting procedures for hopper and sidecasting special-purpose dredges.

4 DRP Benefits Analysis[1]

The DRP benefits analysis was the first detailed study to accurately document and quantify the economic benefits to the user community of a Federal research and development program. Methodology to quantify the economic benefits of research and development programs did not exist at the initiation of the study and was developed and patterned after private-sector techniques that provide for an estimation of uncertainties involved in the process.

Purpose and Scope of Benefits Analysis

The major purpose of this study by Griffis et al. (1995) was to quantify in terms of dollars the economic benefits attributable to the DRP. Each product developed by the DRP was catalogued. Each Corps operation and maintenance dredging project for a 4-year period ending in 1993 was analyzed to determine whether a product of the DRP was used on the project or whether there was the potential for the use of a DRP product if it had not been used on that project. If a product was used or had the potential to be used on a particular dredging project, then the expected benefits to the project using the product were estimated. The benefits were categorized as direct benefits, cost-avoidance benefits, environmental-enhancement benefits, mission-enhancements benefits, and indirect benefits. These benefits were entered into a database. Due to the uncertainty associated with each benefit estimate, each benefit was assumed to follow a specific probability distribution. The sum of all benefits was then subjected to a Monte Carlo analysis, and the relative frequency histogram of the final sum of all benefits was calculated.

Of the 31 Corps Districts with regular dredging programs, 21 were included in the analysis. The other 10 districts are generally riverine

[1] Chapter 4 was extracted from Griffis et al. (1995).

Districts with small dredging workloads. Due to the absence of the Districts with small dredging programs, the overall benefit levels produced by this analysis should be considered to be understated (conservative) estimates.

Categories of Benefits

Based on numerous discussions with knowledgeable District personnel, the categories of benefits were first defined to reflect nationwide District perception and then were refined to reflect appropriateness of DRP product application.

Direct benefits

Direct benefits are economic benefits that actually occurred or potentially could have occurred as a direct result of the use or influence of one or more DRP products versus alternatives for operations and maintenance and/or new work projects. These benefits include:

a. Reduced cycle time for dredging operations.

b. Reduced design and overhead expenses.

c. Improved productivity of operations.

d. Extended disposal-site life.

e. Reduced or eliminated excessive dredging job-cycle scope.

f. Reduced subsurface exploration.

g. Reduced bin-water measurement time.

h. Reduced survey and positioning mobilization.

i. Reduced or eliminated monitoring and administration.

j. Reduced physical-plant expenses.

k. Reduced onshore material placement.

l. Increased material beneficial uses.

m. Reduced or eliminated alternative excessive disposal.

Cost-avoidance benefits

Cost-avoidance benefits are labor, equipment, or legal costs that actually were or potentially could have been prevented as a result of the use or influence of one or more DRP products, including:

a. Reduced or eliminated differing-site-claim legal expenses.

b. Reduced or eliminated added expenses to rectify faulty survey results.

c. Eliminated job operational error.

Environmental-enhancement benefits

Environmental enhancements are economic benefits that actually occurred or potentially could have occurred as a result of performing dredging operations in an environmentally satisfactory manner, or the simplified or standardized regulatory process brought on by use or influence of one or more DRP products, including:

a. Reduced District permit-processing time and overhead.

b. Relaxed environmental windows.

c. Improved resource-agency coordination and cooperation.

d. Reduced endangered-species monitoring.

Mission-enhancement benefits

Mission-enhancement benefits are nonquantifiable economic benefits that actually occurred or potentially could have occurred as a direct result of the use or influence of one or more DRP products versus alternatives for dredging projects involving fixed-cost government physical plant.

Indirect benefits

Indirect cost benefits are economic benefits that actually occurred or potentially could have occurred as an indirect result of the use or influence of one or more DRP products versus alternatives, including:

a. Improved public relations or opinion.

b. Quantified worth of uninterrupted commercial operations.

Data Collection and Organization

Annual recurring benefits

Data were collected from Corps Districts by comparing DRP products on a project-by-project basis. The collection procedure consisted of field visits at which interviews were conducted with personnel directly involved with all phases of dredging operations, including navigation, construction, operations, regulatory, and geotechnical. During these meetings, a comprehensive applicability review of all DRP products per project was performed. Actual or potential project uses of DRP products were quantified into estimates of tangible dollar values. The annual expected continuously recurring economic benefits were calculated for (a) operation and maintenance benefits, (b) Corps-owned plant efficiency benefits, (c) regulatory benefits, (d) claim avoidance benefits, and (e) nonoperation and maintenance benefits.

One-time nonrecurring benefits

It became apparent during the data-collection phase of the analysis that nonrecurring projects were affected equally as much if not more so than annually recurring projects by use of DRP products, on a project-by-project basis. Significant benefits were quantified for both new work and operation and maintenance projects that were not continuous, unlike the majority of operation and maintenance work. These were one-time occurrences on projects with no dredging cycle. A global view of DRP research attributes the end-result benefits of that research to the national Corps dredging program. When a global view of one-time benefits is considered, then one-time benefit projections into the future can be logically justified even if there is no repeatability within any one respective Corps District. Based on a historical analysis of past events, there is no reason to expect that one-time benefits will not occur somewhere each and every year. Estimates for these one-time nonrecurring benefits also were quantified into tangible dollar values.

Forecast Methodology

The estimates of the tangible dollar values attributable to use of DRP products on a project-by-project basis for each Corps District surveyed all contain some degree of uncertainty. While the interview process was designed to be as accurate as possible, the information identified could only represent the moment in time when it was obtained. The dynamic environment in which dredging projects occur lends itself to many changes imposed after the exact moment of identification (including budget, project

scope, time, or resources) that could affect the estimates and create uncertainty.

All estimates contain some element of uncertainty. While there exists a 100-percent certainty of infinitely small benefits, there also exists a very small but finite certainty of infinitely large benefits. The true answer lies somewhere between these extremes. To account for the uncertainty, a Monte Carlo simulation analysis was performed. The analysis developed values of benefits for which there is a 90-percent certainty that the actual or potential benefits will be exceeded (i.e., the benefits developed in the simulation have a probability of 0.90 of being exceeded).

The DRP Monte Carlo analysis was patterned after the private sector and used the conservative forecasting techniques employed by business to predict sales revenue. The assumption here was also made that each benefit would follow a Weibull distribution. The Weibull distribution has a finite lower bound (zero benefits), is skewed conservatively, and has a boundless upper limit (infinite benefits). This distribution has repeatedly been shown to be appropriate for commercial operations that must accurately forecast profits to stay in business.

The Monte Carlo simulation sums the individual project benefits a large number of times (approximately 1,000 for the DRP analysis). At each calculation of a project benefit, a random number from a uniform distribution is assigned. That random number is the probability that the benefits will be less than or equal to a certain amount, which is the inverse of the cumulative Weibull distribution. As each simulation is completed, its value is stored and tallied into a relative frequency histogram.

Projected Benefits

The projected benefits from use of DRP products on Corps dredging operations (Griffis et al. 1995), annualized into 1994 dollars and at the 90-percent confidence level, are as follows:

Annual benefits

a. Annual recurring benefits

1.	Direct benefits	$ 11,200,000
2.	Cost-avoidance benefits	149,000
3.	Environmental-enhancement benefits	413,000
4.	Mission-enhancement benefits	965,000

5.	Indirect benefits	4,677,000
	Total annual recurring benefits	$17,404,000
b.	Annual one-time benefits	
1.	Direct benefits	$ 5,717,000
2.	Cost-avoidance benefits	2,913,000
3.	Nonoperation and maintenance benefits	8,900,000
4.	Indirect benefits	1,517,000
	Total annual one-time benefits	$19,047,000
	TOTAL ANNUAL BENEFITS	$ 36,451,000

Projected 5-year benefits

Based on the U.S. Office of Management and Budget 7.25-percent discount rate, 5-year savings in 1994 dollars by using DRP products on Corps dredging projects and at the 90-percent confidence level, are:

a.	5-year recurring benefits	$ 100,586,000
b.	5-year one-time benefits	101,141,000
	TOTAL PROJECTED 5-YEAR BENEFITS	$ 201,727,000

5 Synopsis

The research described in this summary report of Technical Area 5 of the DRP, "Management of Dredging Projects," pertains to the necessity for proper management of open-water dredged-material disposal sites, provides guidance for capping contaminated sediments, and develops engineering designs for nearshore berms as an alternative to open-water placement. A chronology of Corps hopper-dredging activities since 1954 also was provided. Finally, the first benefits analysis of a Federal research and development program was conducted for the DRP.

Framework for Management of Open-Water Dredged Material Disposal Sites

Continued use of aquatic sites for placement of dredged materials may depend on the Corps' ability to effectively manage dredged-material placement sites, as well as the perception of how well the Corps' management policies and practices protect human health and the aquatic environment. Expanded guidance on managing open-water dredged material placement sites is being prepared by USACE and the USEPA. Moreover, recent amendments to the MPRSA (Ocean Dumping Act) call for specific site-management activities and preparation of site-management plans for all ocean placement sites. The principal benefits from effective site management are derived through ensuring the long-term availability of the placement site: potential project delays are avoided; the costs of identifying and designating/specifying alternative sites are saved; and potential increases in transportation costs or other costs relative to alternative sites are averted.

USACE approach

The USACE approach to managing open-water sites focuses on providing all necessary information for site managers to make informed decisions. A written site-specific management plan can greatly facilitate management action over the extended use of the placement site. The best

plan will be flexible and revolving, and written plans will need to be updated periodically.

Site monitoring

Monitoring is an essential component in the overall management of the site. The intensity of monitoring will increase with the volume of sediments, the rate of placement, the number of site users, the variance of sediments, the presence of man-made contaminants in the sediment, and resources of concern in the vicinity of the placement site. Results of monitoring studies can be used to verify assumptions and predictions or to provide a basis for modifying the decision process (i.e., developing more or less stringent decision guidance).

Specialized management procedures

Material that is not suitable for unrestricted open-water disposal (contaminated) can sometimes be disposed at open-water sites by using specialized procedures such as time, location, and volume modifications; submerged discharge; lateral containment; thin-layer placement; capping; or in situ treatment. The site-management plan should identify the specialized tools and management practices appropriate for the site and specify the criteria leading to the use of such practices.

Capping Contaminated Sediments Disposed in Open Water

If a sediment is found to be unsuitable for open-water disposal because of potential contaminant effects, management options aimed at reducing the release of contaminants to the water column during disposal and/or subsequent isolation of the material from benthic organisms may be considered. Such options include capping of contaminated material with suitable clean material.

Design of capping projects

Capping must not be viewed merely as a form of restricted open-water placement. A capping operation is treated as an engineered project with carefully considered design, construction, and monitoring to ensure that the design objectives are achieved. Design requirements for contaminated-material capping include:

a. Gather project data.

b. Characterize contaminated material.

c. Select potential capping site.

d. Select and characterize capping material.

e. Select equipment and placement technique for contaminated material.

f. Select equipment and placement technique for capping material.

g. Select navigation and positioning equipment and controls. At this point, evaluate compatibility of site, materials, and equipment.

h. Predict water-column mixing and dispersion effects of contaminated sediment during placement.

i. Determine required cap thickness.

j. Evaluate spread and mounding of contaminated and capping material during placement.

k. Evaluate stability, erosion, and consolidation of capping material.

l. Develop a disposal-site monitoring plan.

Considerations for capping-material placement

Placement of capping material should be accomplished so that the deposit forms a layer of required thickness over the deposit of contaminated material. The determination of the minimum required cap thickness is dependent on the physical and chemical properties of the contaminated and capping materials, and the potential for bioturbation of the cap by aquatic organisms. The thickness for chemical isolation plus the thickness for bioturbation is considered the minimum required cap thickness.

Effectiveness of capping

Capping appears to offer an effective management option for the long-term isolation of contaminated dredged material from the surrounding environment. Evidence on the ability to create caps and on the effectiveness of capping is rapidly increasing as follow-up surveys of such sites continue. Many of the questions about the effectiveness of properly designed caps to contain contaminants over long time periods can now be answered with greater certainty based on results of follow-up surveys.

Design Guidance for Nearshore Berms

Nearshore-berm construction is a less expensive, although complex, alternative to conventional open-water placement, and it provides additional beneficial uses of dredged material. To ensure berm effectiveness, construction cannot be treated simply as a modification of conventional open-water disposal operations. The berm must be considered an engineered structure requiring a design template that can be verified and constructed, with provisions for periodic maintenance throughout the design life.

Feeder berms

Feeder berms are constructed of clean sand placed in relatively shallow water to enhance adjacent beaches and nearshore areas by mitigating erosive wave action and by providing additional material for the littoral system. If a berm is placed in sufficiently shallow water and with sufficiently high relief, the higher erosive waves accompanying storms will break on the berm's seaward slope and crest.

Stable berms

Stable berms are intended to be permanent features constructed in deeper water outside the littoral environment. They may function to attract fish as well as reduce wave energy incident to the coast. Material from the berm is not expected to be transported to the littoral system and beach. Berms designed to be stable may be constructed of a wider range of materials and grain sizes than feeder berms.

Sacrificial berms

This berm placed in shallower waters would differ from a feeder berm in that it would be constructed of finer grain material, which would likely be carried offshore by waves, possibly nourishing the offshore profile and flattening its slope. This is in contrast to a feeder berm, which may nourish the beach. The sacrificial berm will expend wave energy, sparing the shoreline for as long as the berm remains in place.

Berm design

Material quality and quantity evaluations concern dredged material beach compatibility, mounding properties, and available volume. Local wave conditions will determine the depth of placement for supplementing the supply of littoral material by feeder berms. Material to be placed at the design depth and crest elevation will require suitable dredge equipment, usually a split-hull hopper dredge or barge. After the berm crest

elevation has been decided upon, it is imperative that berm length, end slopes, and crest width be developed to avoid wave-energy focusing and adverse impacts on the adjacent shoreline. Design guidance has been developed by Burke and Allison (1992) and Pollock and Allison (1993) that adequately covers these parameters. Tools for evaluation of berm geometry and estimation of berm wave attenuation benefits have subsequently been developed by WES (Pollock, unpublished data).

Corps of Engineers Hopper Dredging, 1954-1994

In 1954, the Office of the Chief of Engineers published *The Hopper Dredge: Its History, Development, and Operation.* This 400-page book, with its hard red-cloth cover, chronicled the history of the U.S. Army Corps of Engineers hopper-dredging program and described in detail the evolution and application of 100 years of hopper-dredge technical advances. This book, referred to as the "Red Book," became valuable to those in offices and onboard ships who were involved in planning and operating the Corps' seagoing hydraulic hopper-dredge fleet. It also became popular in Europe where it was used by dredge masters and others working to expand their knowledge and expertise in hopper dredging.

The purpose of *Corps of Engineers Hopper Dredging, 1954-1994* is to describe major events in the Corps of Engineers hopper dredging program since publication of the Red Book. Hopper-dredge activities, programs, and policies are addressed, as well as operating characteristics and technologies pertaining to hopper dredging. Additionally, each of the four currently active Corps hopper dredges is discussed in detail.

When the Red Book was written, the Corps owned and operated 20 hopper dredges. The Corps' fleet was spread throughout the coastal United States, with six hopper dredges on the west coast, eight on the west coast, three stationed on the gulf coast, and three assigned to the Great Lakes. No private-industry hopper dredges existed in the United States. Indeed, the construction of 10 of these Corps hopper dredges between 1942 and 1949 indicated the U.S. government was gearing up to continue its traditional role of primary responsibility for the construction and maintenance of navigation channels in the United States.

By 1990 the face of hopper dredging in the United States had changed significantly. Policy changes within the Corps hopper-dredging program and external events, such as new environmental regulations, had resulted in a very different hopper-dredging program. The Corps hopper-dredge fleet had shrunk to four active dredges, all of them constructed since 1967: two on the west coast (*Yaquina and Essayons*); one on the east coast (*McFarland*); one on the gulf coast (*Wheeler*). For FY92, the Corps dredged 22 million cu yd with those four dredges. Fifteen private-industry

hopper dredges vied for the remaining hopper dredging necessary to keep coastal and inland navigation channels at authorized depths. This meant 35.5 million cu yd of new work and maintenance dredging was performed by private industry. A revised EM to replace the existing EM 1125-2-312 was prepared (U.S. Army Corps of Engineers 1994). This new EM provides guidance on current operating and reporting procedures for hopper and sidecasting/special-purpose dredges.

DRP Benefits Analysis

The DRP benefits analysis was the first detailed study to accurately document and quantify the economic benefits to the user community of a Federal research and development program. The methodology to quantify the economic benefits of research and development programs did not exist at the initiation of the study. Griffis et al. (1995) developed a methodology, patterned after private-sector techniques, that provided for an estimation of uncertainty involved in the process.

Each Corps operation and maintenance dredging project for a 4-year period ending in 1993 was analyzed to determine whether a product of the DRP was used on the project or whether there was the potential for the use of a DRP product if it had not been used on that project. If a product was used or had the potential to be used on a particular dredging project, then the expected benefits to the project from using the product were estimated.

Forecast methodology

Estimates of the tangible dollar values attributable to use of DRP products on a project-by-project basis for each Corps District all contain some degree of uncertainty. To account for the uncertainty in the estimates, a Monte Carlo simulation analysis was performed. The Monte Carlo simulations utilized a Weibull distribution that has repeatedly been shown to be appropriate for conservative private-sector enterprises. The analysis developed values of benefits for which there is a 90-percent certainty that the actual or potential benefits will be exceeded (i.e., the benefits developed in the simulation have a probability of 0.90 of being exceeded).

Benefits

Annual benefits. The estimated benefits from use of DRP products on Corps dredging operations (Griffis et al. 1995), annualized into 1994 dollars, and at the 90-percent confidence level, are as follows:

Annual Recurring Benefits	$ 17,404,000
Annual One-Time Benefits	19,047,000
TOTAL ANNUAL BENEFITS	$ 36,451,000

Projected 5-year benefits. Based on the U.S. Office of Management and Budget 7.25-percent discount rate, 5-year savings in 1994 dollars by using DRP products on Corps dredging projects and at the 90-percent confidence level, are:

5-Year Recurring Benefits	$ 100,586,000
5-Year One-Time Benefits	101,141,000
TOTAL PROJECTED 5-YEAR BENEFITS	$ 201,727,000

References

Bokuniewicz, H. (1989). "Behavior of sand caps on subaqueous dredged sediment disposal sites," *Scientific Monitoring Strategies for Ocean Waste Disposal* 4, Krieger Publishing, Malabar, FL.

Burke, C. E., and Allison, M. C. (1992). "Length and end slope considerations, interim design guidance update for nearshore berm construction," Dredging Research Technical Notes DRP-5-06, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Burke, C. E., and Williams, G. L. (1992). "Nearshore berms—wave breaking and beach buildings." *Proceedings, Ports '92.* U.S. Section of Permanent International Association of Navigation Congresses (PIANC), Seattle, WA, 96-110.

Burke, C. E., McLellan, T. N., and Clausner, J. E. (1991). "Nearshore berms—update of the United States experience." *Proceedings, Accessible Harbours, CEDA-PIANC Conference 1991.* (Incorporating CEDA Dredging Days), Section A5, Amsterdam, The Netherlands.

Dean, R. G. (1991). "Equilibrium beach profiles: Characteristics and applications," *Journal of Coastal Research* 7(1), 53-84.

Griffis, F. H., Jettmar, C. E., Pagdadis, S., and Tillman, R. K. (1995). "Dredging Research Program benefits analysis," Technical Report DRP-95-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hales, L. Z. (1995). "Accomplishments of the Corps of Engineers Dredging Research Program," *Journal of Coastal Research* 11(1), 68-88.

Johnson, B. H. (1990). "User's guide for models of dredged material disposal in open water," Technical Report D-90-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

McLellan, T. N. (1990). "Engineering design considerations for nearshore berms," Dredging Research Technical Notes DRP-5-01, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

McLellan, T. N., Kraus, N. C., and Burke, C. E. (1990). "Interim design guidance for nearshore berm construction," Dredging Research Technical Notes DRP-5-02, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

McNair, E. C., Jr. (1988). "The Dredging Research Program," Dredging Research Information Exchange Bulletin DRP-88-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1-5.

______. (1989). "Dredging Research Program of the U.S. Army Corps of Engineers." *Proceedings, XII World Dredging Congress.* Orlando, FL, 44-50.

Ogden Beeman and Associates, Inc. "Corps of Engineers hopper dredging, 1954-1994," in preparation, Ogden Beeman and Associates, Inc., Portland, OR.

Palermo, M. R. (1991). "Equipment and placement techniques for capping," Dredging Research Technical Notes DRP-5-05, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R., Fredette, T. J., and Randall, R. E. (1992). "Monitoring considerations for capping," Dredging Research Technical Notes DRP-5-07, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R., Randall, R. E., and Fredette, T. J. "Guidance for subaqueous dredged material capping," in preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pollock, C. B., and Allison, M. C. (1993). "Berm crest width considerations, interim design guidance update for nearshore berm construction," Dredging Research Technical Notes DRP-5-08, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pollock, C. E., Allison, M. C., and Williams, G. L. (1993). "Designing nearshore berms to optimize wave attenuation." *Proceedings of the Hilton Head Island, South Carolina, U.S.A. International Coastal Symposium.* P. Bruun, ed., Hilton Head Island, SC, 162-167.

Scheffner, N. W. (1992). "Dispersion analysis of Humboldt Bay, California, interim offshore disposal site," Miscellaneous Paper DRP-92-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Scheffner, N. W., and Tallent, J. R. (1994). "Dispersion analysis of Charleston, South Carolina, ocean dredged material disposal site," Miscellaneous Paper DRP-94-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sumeri, A., and Romberg, P. (1991). "Contaminated bottom sediment capping demonstration in Elliott Bay." *Proceedings, Conference on Puget Sound Research '91.* Seattle, WA.

Sumeri, A., Fredette, T. J., Kullberg, P. G., Germano, J. D., Carey, D. A., and Pechko, P. (1994). "Sediment chemistry profiles of capped dredged sediment deposits taken 3 to 11 years after capping," Dredging Research Technical Notes DRP-5-09, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers. (1990). "Corps of Engineers Marine Engineering Board," Engineering Regulation ER 15-2-6, Department of the Army, Washington, DC.

______. (1993a). "Policy Guidance Letter No. 40; Development and financing of dredged material management studies," CECW-PA/OD, Department of the Army, Washington, DC.

______. (1993b). "Policy Guidance Letter No. 42, Additional guidance on financing of dredged material management studies," CECW-PA/OD, Department of the Army, Washington, DC.

______. (1994). "Manual of instructions for hopper/sidecasting dredge operations and standard reporting procedures," Engineer Manual 1125-2-312, Washington, DC.

U.S. Environmental Protection Agency/U.S. Army Corps of Engineers. (1992). "Evaluating environmental effects of dredged material management alternatives—a technical framework," U.S. Environmental Protection Agency/Department of the Army, Washington, DC.

Walls, B. E., Lemlich, S. K., Wright, T. D., Clausner, J. E., and Mathis, D. B. "Open-water placement of dredged sediment: A framework for site management," in preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Appendix A Design and Management Sequence for Capping Projects

The following is an outline for the sequential actions required to accomplish a capping operation; more detailed information is included in Palermo, Randall, and Fredette (in preparation)[1] from which this appendix was extracted. Figure A1 is a flowchart for the procedure. The parenthetical numbers in the text refer to similar numbers in Figure A1.

(1) Gather project data. Gather and evaluate existing data that normally include surveys of the dredging area, characteristics of the contaminated sediment, and characteristics of potential placement sites (e.g., area erosion trends, wind-wave resuspension, wave-current interaction effects). Data on the contaminant status of the material to be dredged may exist. These data may include results of physical, chemical, and biological tests required under Section 404 of the Clean Water Act (CWA) or Section 103 of the Marine Protection, Research, and Sanctuaries Act (MPRSA). Data on potential placement sites may vary. Bathymetry, currents, and bottom sediment characterization are normally available for open-water sites under consideration.

Once existing data have been gathered, three main aspects of capping design must be examined: characterization and placement of the contaminated material; characterization and placement of the capping material; and capping site under consideration. Each

[1] References cited in this appendix are included in the list that follows the main text.

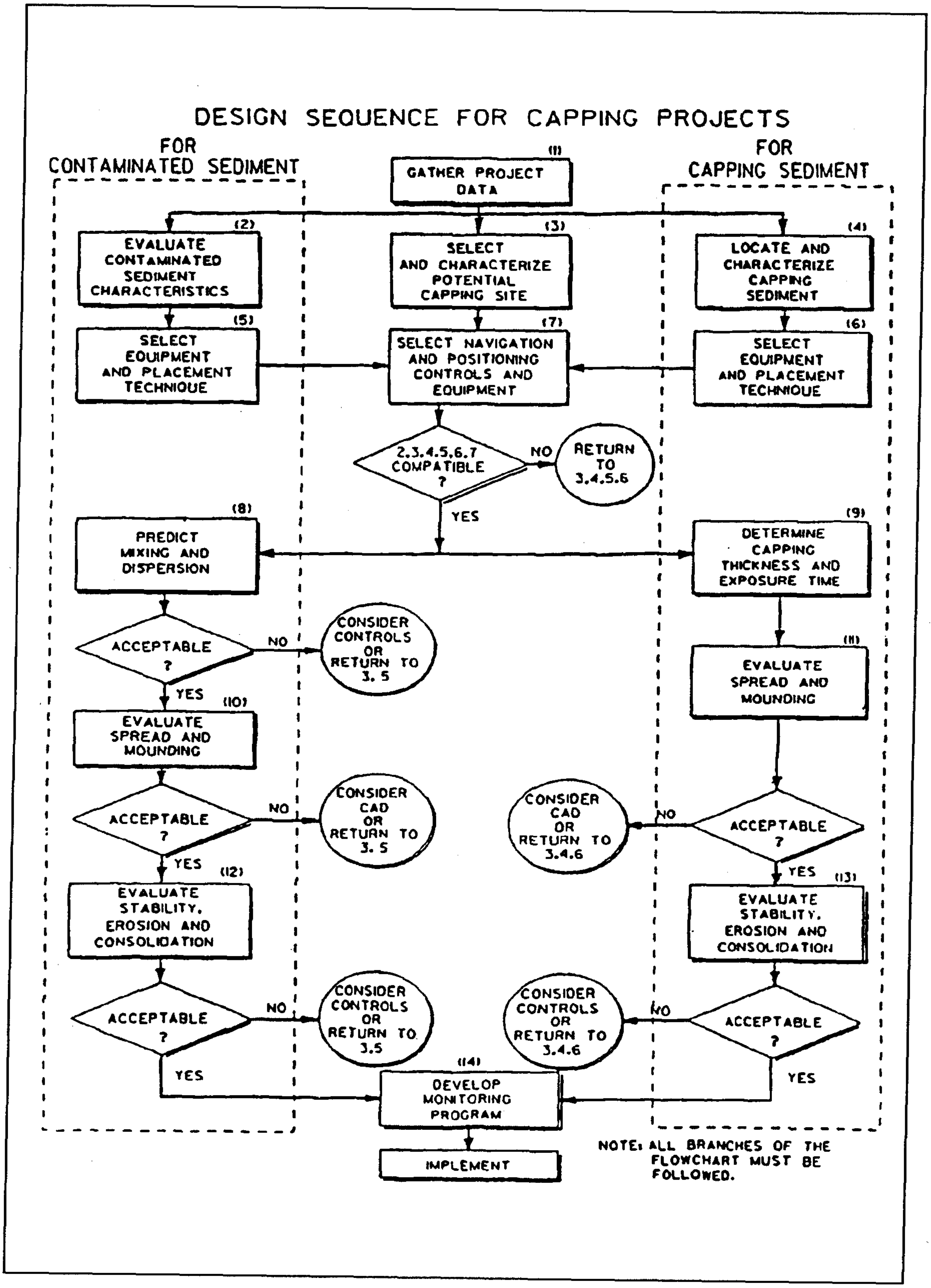

Figure A1. Design procedure for a capping project for open-water disposal of dredged material

of these aspects must be examined initially in a parallel fashion. Further, the interrelationship and compatibility of these three aspects of the design are critical.

(2) Characterize contaminated sediment. The contaminated sediment must be characterized from physical, chemical, and biological standpoints. Physical characteristics are of importance in determining the behavior of the material during and following placement at a capping site. In situ volume to be dredged, in situ density (or water content), shear strength, and grain-size distribution are needed for evaluations of dispersion and spread during placement, mounding characteristics, and long-term stability and resistance to erosion. These data should be developed using standard techniques.

Capping as an alternative is usually considered only after determining that benthic effects resulting from unrestricted open-water placement would be unacceptable. Therefore, some chemical and biological characterization of the contaminated sediment is normally performed as a part of the overall evaluation for suitability for open-water placement.

(3) Selection of a potential capping site. The selection of a potential site for a capping operation is subject to the same constraints and trade-offs as any other open-water placement site. The major considerations in site selection include: bathymetry, currents, water depths, water-column density stratification, erosion/accretion trends, bottom sediment characteristics, and operational require-ments such as distance and wave climate. How-ever, in addition to normal considerations, if possible, the capping site should be in a relatively low-energy environment with relatively low poten-tial for erosion of the cap. Greater cap thickness would be required in a high-energy environment.

Bathymetry forming a natural depression will tend to confine the material, resulting in a contained aquatic disposal (CAD) project. Placement of material on steep bottom slopes should generally be avoided for a capping project. Water-column currents affect the degree of dispersion during placement and the location of the mound with respect to the point of discharge. Of more importance are the bottom currents that could potentially cause

resuspension and erosion of the mound and cap. The effects of storm-induced waves on bottom current velocities must be considered. The deeper the water at the site, the greater the potential for water entrainment and dispersion during placement. However, deeper water depths also generally provide more stable conditions on the bottom with less potential for erosion.

(4) Selection and characterization of capping sediment. The capping sediment used in a project may be a matter of choice. However, for economic reasons, a capping sediment is usually taken from an area that also requires dredging or is considered advance maintenance dredging. If this is the case, there may be a choice between projects. Scheduling of the dredging is an important consideration. In other cases, removal of bottom sediments from areas adjacent to the capping site may be considered.

Characterization of the capping sediment is the same as described above for the contaminated sediment. However, the capping sediment must be one that is acceptable for unrestricted open-water placement (i.e., clean sediment). The evaluation of a potential capping sediment for open-water placement acceptability must be accomplished using appropriate techniques under either CWA or MPRSA. Physical characteristics of the capping sediment are also of particular interest in capping design. Density (or water content), grain-size distribution, and cohesiveness of the capping sediment must be evaluated. The characteristics of the capping sediment should be compatible with the contaminated sediment, considering the placement technique for both. Previous studies have shown that both fine-grained materials and sandy materials can be effective capping materials.

(5) Equipment and placement technique for contaminated sediment. A variety of equipment types and placement techniques have been used for capping projects. The important factors in the placement of contaminated material are reducing water-column dispersion and bottom spread to the greatest possible extent. This minimizes the release of contaminants during placement and provides for easier capping. For level-bottom capping (LBC), the dredging equipment and placement technique for contaminated sediment must produce a tight com-

pact mound. This is most easily accomplished with mechanical dredging and barge release. If CAD is under consideration, hydraulic placement of the contaminated material may be acceptable.

Specialized equipment and placement techniques can also be considered to increase control during placement and to reduce potential dispersion and spread of contaminated material. These might include use of submerged diffusers or submerged discharge points for hydraulic pipeline placement, hopper dredge pump-down with diffuser, or gravity-fed tremie for mechanical or hydraulic placement.

(6) Equipment and placement technique for capping sediment. The major design requirement in the selection of equipment and placement of the cap is the need for controlled, accurate placement and the resulting density and rate of application of capping material. In general, the cap material should be placed so that it accumulates in a layer covering the contaminated material. The use of equipment or placement rates that might result in the capping material displacing or mixing with the previously placed contaminated material must be avoided. Placement of capping material at equal or less density than the contaminated material usually meets this requirement. However, this is not always the case (e.g., sprinkling sand over fine-grained material).

Use of specialized equipment and placement techniques can be considered to increase control of capping-material placement. The movement of submerged diffusers, energy dissipaters, submerged discharge points, or tremies can be controlled to spread capping material over a specified area to a required thickness. Incremental opening of split-hull or multi-compartment barges and dredges, along with controlled movement of the barges and dredges during surface release, has been used for mechanically and hydraulically dredged sandy capping material. Direct pump-out of hopper dredges over the side has also been used for cap placement. Energy dissipaters for hydraulic placement of capping materials have been used successfully.

(7) Selection of navigation and positioning equipment and controls. Placement of both the contaminated and capping material must be carefully controlled,

regardless of the equipment and placement technique selected. Electronic positioning systems, taut-moored buoy, mooring barges, various acoustical positioning devices, differential global positioning system, and computer-assisted real-time helmsman's aids should be considered in selecting the placement technique.

Evaluate compatibility of site, materials, and equipment. At this point in the design, the contaminated material has been characterized, a capping sediment has been selected and characterized, equipment and placement techniques have been selected for both materials, and navigation and positioning needs have been addressed. These essential components of the design must now be examined as a whole with compatibility in mind.

If the components are compatible, additional and more detailed design requirements can be addressed. If there is a lack of compatibility at this point, a different capping site (3), a different capping sediment (4), or different placement equipment and techniques (5, 6) must be considered. A close examination of the project design components at this decision point is essential before performing the more detailed and costly evaluations that come later in the design process.

(8) Predict water-column mixing and dispersion effects of contaminated sediment during placement. If water-column effects during placement of the contaminated material are of concern, an evaluation of the suitability of the material from the standpoint of water-column effects must be performed. This evaluation involves the comparison of predicted water-column contaminant concentrations with water-quality criteria and predicted water-column dredged material concentrations with bioassay test results. Use of available mathematical models (Johnson 1990) and/or case-study field monitoring results to predict the water-column dispersion and concentrations is an integral part of such evaluations. In addition, the prediction indicates what portion of the contaminated material is released during placement and not capped. Initial deposition and spread of material are evaluated in determining the mounding characteristics for the entire contaminated material volume to be placed. If water-column release is unacceptable, alternatives must be considered:

control measures to reduce the potential for water-column effects; selection of other dredging equipment and placement techniques (5); or use of another capping site (3).

(9) Determine the required cap thickness. The cap must be designed to isolate the contaminated material from the aquatic environment, both chemically and biologically. Determination of the required cap thickness is dependent on the physical and chemical properties of the contaminated and capping materials, the potential for bioturbation of the cap by aquatic organisms, and the potential for consolidation and erosion of the cap material. The minimum required cap thickness is considered to be the thickness required for chemical isolation plus that thickness of bioturbation associated with organisms likely to colonize the site in significant numbers. The integrity of the cap from the standpoint of physical changes in cap thickness and long-term migration of contaminants through the cap should also be considered. The potential for a physical reduction in cap thickness due to the effects of consolidation and erosion (12, 13) can be evaluated once the overall size and configuration of the capped mound is determined. The design cap thickness can then be adjusted such that the minimum required cap thickness is maintained.

(10) (11) Evaluate spread and mounding. The mound geometry, including contaminated material mound and cap, will influence the design of the cap and volume of capping material required. The smaller the footprint of the contaminated material as placed, the less volume of capping material is required to achieve a given cap thickness. For LBC sites, the spread and development of the contaminated material mound is dependent on the physical characteristics of the material (grain size and cohesion) and the placement technique used (hydraulic placement results in greater spread than mechanical placement). Assuming that the material from multiple barge loads or pipeline can be accurately placed at a single point, the angle of repose taken by the material and the total volume placed dictate the mound spread. Low density fine-grained material, even if mechanically dredged, can move beyond the main mound, forming a thin apron (<0.3 m thick) that can extend hundreds of meters beyond the main mound.

(12) (13) Evaluate stability, erosion, and consolidation. The deposit of contaminated dredged material must also be stable against excessive erosion and resuspension of material before placement of the cap. The cap material must be stable against long-term erosion for the required cap thickness to be maintained. The potential for resuspension and erosion is dependent on bottom-current velocity, potential for wave-induced currents, and sediment particle size and cohesiveness. Site-selection criteria as described above normally result in a site with low bottom-current velocity and little potential for erosion. However, if the material is hydraulically placed, a thorough analysis of the potential for resuspension and erosion must be performed. Conventional methods for analysis of sediment transport can be used to evaluate erosion potential. These methods can range from simple analytical techniques to sophisticated numerical modeling (Scheffner 1992; Scheffner and Tallent 1994).

Consolidation of the mound of contaminated material needs to be examined for its effect on mound slopes and volume occupied within the disposal site. In general, consolidation of the contaminated mound will result in more stable conditions. The same is true for consolidation of the cap material. However, consolidation of the cap results in a reduced cap thickness. Therefore, the potential for cap consolidation must be considered in the overall design of the cap thickness.

If the potential for erosion and consolidation of either the contaminated material or cap is unacceptable, consideration must be given to selection of an alternative disposal site (3), alternative capping sediment (4), or alternative placement techniques (5, 6).

(14) Develop a monitoring program. A monitoring program must be considered as a part of any capping project design. The main objectives of monitoring normally are to ensure the following: the contaminated sediment is placed as intended and with acceptable levels of contaminant release; the cap is placed as intended and the required capping thickness is maintained; and the cap is effective in isolating the contaminated material from the environment. Monitoring plans for capping projects need to include an intensive effort during and shortly after

placement operations and immediately after any unusual climatic events (e.g., hurricane, severe storm, etc.), with a declining level of effort in future years if no adverse effects are detected. Physical, chemical, and biological elements may be included in a monitoring plan. In all cases, the objectives of the monitoring effort and any remedial actions to be considered as a result of the monitoring must be clearly defined as a part of the overall project design (Palermo et al. 1992).

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A framework for long-term management of open-water sites based on guidance from Corps Headquarters in response to amendments of the Marine Protection, Research, and Sanctuaries Act (Ocean Dumping Act) was developed. A chronology of major events in the Corps' hopper-dredging program since publication of the "Red Book" in 1954 was compiled. The Dredging Research Program (DRP) benefits analysis accurately documented and quantified the tax dollars that could be saved by using products of the DRP. It was determined at the 90-percent confidence level that in 1994 dollars, annual recurring benefits of $17 million and annual one-time benefits of $19 million could accrue, and 5-year recurring and 5-year one-time benefits in excess of $100 million each could result from use of DRP products.

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